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Above and Below Ground Competition for Resources in a Sesbania and Maize Agroforestry System

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Abstract: This study was conducted at ICRAF Field Research Station in Machakos, Kenya. It was designed to determine the relative importance of above and below ground competition between three sesbanias (*Sesbania goetzei, Sesbania macrantha, and Sesbania sesban*) and maize (*Zea mays*). To separate above and below ground competition, guy wiring and root barrier were used to remove shade and root competition, respectively, for each of the *Sesbania* species. Free growth, where both roots and shade are present, was also used for each species. Sole maize was used as control. The treatments were arranged in a randomized complete block design with three replications. The three *Sesbania* species were intercropped with maize; one row of trees followed by seven rows of maize in each plot. Yield components of maize and light interception were monitored for four months. The results indicated that both *S. macrantha and S. sesban* negatively affected maize growth and yield. Maize height and yield increased with distance from the trees.

Key words: Agroforestry; interactions; competition; grain yield; light interception

INTRODUCTION

Sesbanias are indigenous fast growing multipurpose trees in Sudan. They are widely distributed in the tropical and subtropical regions. The genus *Sesbania* belongs to subfamily Papilionoidea of the Leguminasae and is placed in the order Robinieae. It is generally found in dry-wet tropics with annual rainfall of 500 – 2000 mm. Sesbanias have a variety of uses, which include fodder, medicine, green manure, fuel wood and shade for under story. They are suitable for soil conservation and enhancing soil fertility through rhizobial nitrogen fixation.

Agoforestry systems and practices have gained a particular importance in tropical and arid zones to secure sustainable land use. Systems that involved simultaneous arrangement of woody perennials and annual crops are complex by nature. In such systems, competition between components is inevitable. However, when trees and crops complement each other at least the productivity of one of them is improved (Jordan 2004). Research is needed to understand interactions between trees and herbaceous crops and to suggest the best choice of compatible system components and their arrangements.

Tree-crop competition for light and space is known as above ground and for water, nutrient and space as below ground. The tree-crop interactions may result in a positive or negative effect depending on soil, climatic conditions, species involved (plant components) and management of the system (Anderson and Sinclaire 1993). Positive interactions improve water and nutrients status under tree canopy, hence increasing productivity of the crops (Gyenge *et al.* 2002). In semi-arid and sub-humid environments where water is often limited, below ground competition for water and nutrients greatly determines the success or failure of agroforestry systems. Wanvestreat *et al.* (2004) found that under dry conditions, competition is mostly for water. The potential of an individual to grow and reproduce depends on its ability to compete with others in the system (Monteith *et al.* 1991). The power of competition between plants depends on their root characteristics, canopy and growth rate. The extent of competition between trees and crops depends on the tree species characteristics, planting density, size and stage of development, site conditions and management (Nair 1993).

Trees used in agroforestry should be able to utilize nutrients from different niches than those utilized by the crops, i e., shallow rooted trees compete with associated crops for nutrient in the soil surface (Chirwa *et al.* 2006). In a study on *Populus tremuloides* Michx, Powell and Bork

(2007) found that soil water was greater in the open than under either a full or partial canopy.In an intercropping system of white clover and cereals, the interaction between the two species was dominated by competition for below ground resources (Thorsted *et al.* 2006).

Although many studies have indicated that both above and below ground interactions accounted for crop yield reduction (Corlett *et al.* 1992; Yamoah 1991; Ong *et al*. 1992), yet there is a need to identify the relative importance and extent of above and below ground competition.

The objective of this study was to quantify above and below ground competition in three S*esbania* species and maize agroforestry system.

MATERIALS AND METHODS

This study was conducted at ICRAF Field Research Station at Machakos (01^{o} 33$^{/}$ N; 37^{o} 14$^{/}$ E; 1660 m asl), Kenya. The average rain fall in the area is 740 mm, which comes in two rainy seasons; the long and the short rain. The average daily temperature is 20 C^{o} and the relative humidity is 56% – 91%. The soil of the experimental site (Table 1) is well-drained, dark reddish brown sandy clay, with a pH of 6.0 – 6.5.

The experiment consisted of four treatments; namely, sole crop (control), guy wiring, root barrier and free growth. The four treatments were tested with three sesbanias (*Sesbania goetzei, S. macrantha and S. sesban)* giving the following ten treatment combinations: Sole maize crop (control); *Sesbania goetzei* free growth, guy wiring and root barrier; *S. macrantha* free growth, guy wiring and root barrier and *S. sesban* free growth, guy wiring and root barrier. The trees were one year old at the beginning of the experiment. Maize was planted in the short rain season in Kenya (0ctober – December).

Table 1. Some soil characteristics of the experimental site, ICRAF Field Research Station at Machakos, Kenya

Soil properties	Soil depth (cm)		
	15	30	60
pH	6.30	6.30	6.40
Ex. Ca	4.30	5.10	5.20
Ex. Mg	1.20	1.50	1.70
Ex. K	0.43	0.26	0.24
Ex. P	7.00	3.00	1.60
Soluble C	0.84	0.77	0.67
Clay (%)	26.30	32.0	35.70
Sand (%)	64.30	58.00	53.70
Silt (%)	9.00	9.30	11.00

Ex. = Exchangeable

Each of these treatment combinations was accommodated in a plot of 5×10 m with a single row of sesbania trees per plot and seven rows of maize, arranged in a randomized complete block design and replicated three times. The tree intra-row spacing was 0.5 m, and rows were oriented east-west. Sesbanias branches on the southern side of trees were trimmed to avoid shading the adjacent plot. The maize crop (Katumani composite) was sown at 0.75 m inter-row spacing and 0.3 m intra-row. Trenches of 1 m deep were dug and lined with polythene sheets to eliminate root competition. Guy wiring was used to eliminate the shade effect of sesbanias (from the northern side) on the adjacent maize crop.

All cultural practices for maize (sowing depth, spacing, singling, weeding, fertilizer application etc…), were the same for all treatment combinations. Data on the following parameters of the maize crop were collected: Plant height, flowering percentage, number of plants/row, number of cobs/row, grain yield (kg/row), stover yield (kg/row), average weight of cobs, grain and stover yield (kg/plot).

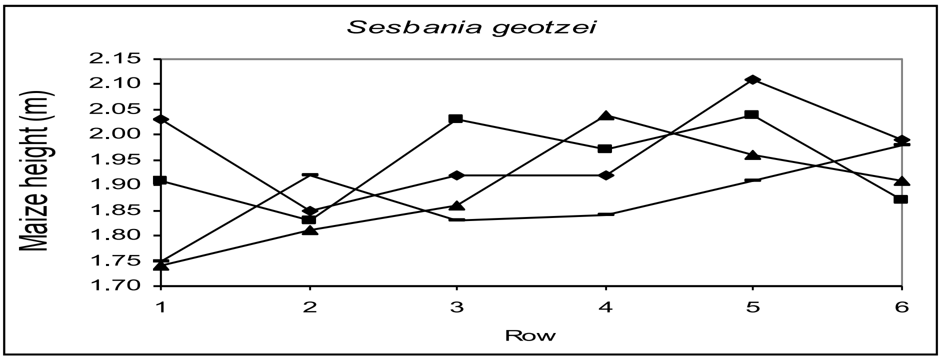
Light interception by the plants was determined from photosynthetically active radiation (PAR), measured by Sunfleck Ceptometer.

Collected data were analyzed statistically for plot means using SAS (1990), and significant differences at P = 0.05 confidence level were tested by orthogonal polynomial contrast (Peterson 1985)

RESULTS AND DISCUSSION

The results revealed an increase in maize plant height with increasing distance from the tree rows (Fig.1).The free tree growth of *S. macrantha* resulted in the lowest maize height up to row 5 compared to root barrier and guy wiring treatments. Similar results were reported by Corlett *et al.* (1992). The root barrier treatment of the same species, *S. macrantha,* produced taller maize in rows 2, 3, 4, 5 and 6. Below ground competition had more effect on the reduction of maize height, since root barrier treatment had completely eliminated root competition except in the first row. Reduction in maize height in the root barrier treatment in the first row could be attributed to the presence of tree roots during the dry season, i.e., before installing the root barrier. This result agrees with the findings of Chirwa and Ong (2007) that lower available soil water at the beginning of the cropping season under trees is a result of water depletion by trees during the dry season. This can also be due to the penetration of roots below the root barrier. This indicates that maize height is sensitive to both above and below ground competition.

Free growth and guy wiring treatments of *S. sesban* showed similar effects on maize height in the first row. In the second, third and fourth rows, free growth treatment resulted in significantly ($P \leq 0.05$) shorter maize plants than in other treatments (Fig.1).This indicates also that the reduction in maize height by *S. sesban* could be attributed to above and below ground competition; with root competition more detrimental to height growth.



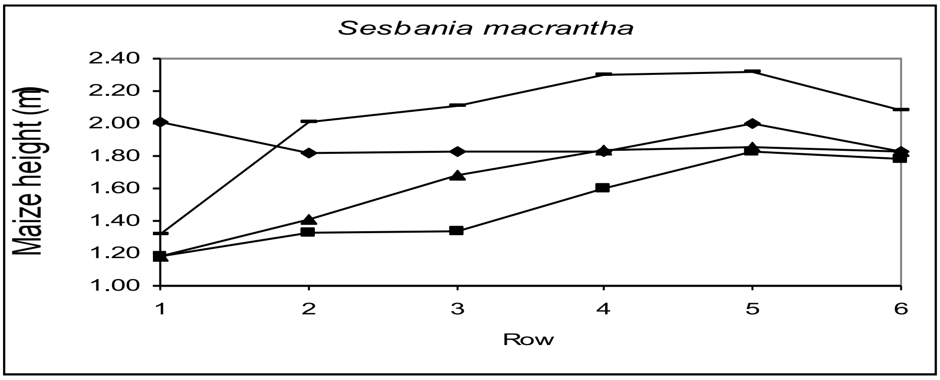


Figure 1 Effect of treatments on maize height (m) 60 days after sowing in a sesbania/maize agroforestry system

The flowering of the maize inter-crop was delayed by the presence of trees. Sole maize crop reached 50% flowering in 5 to 6 weeks, whereas all other treatment combinations delayed the flowering of maize by 6 to 8 weeks from sowing (Table 2). The free growth and guy wiring of *S. macrantha* and *S. sesban* significantly reduced flowering percentage of maize in the first three rows compared to sole maize (Table 2). However, the effect of free growth of *S. sesban* extended up to the fourth maize row. The root barrier effect on flowering percentage was observed in the first row and first and second rows of *S. macrantha* and *S. sesban* treatments, respectivehy. Guy wiring did not produce a positive effect on flowering percentage of maize compared to tree free growth.

Table 2. Effect of treatments on flowering percentage of maize, 42 days after sowing

Treatment	Row number					
	1	2	3	4	5	6
Sole maize	44.4 a	51.9 a	55.6	56.8 ab	58.0 a	53.1 a
S. goetzei						
Free growth	39.5 a	35.8 ab	48.1 ab	55.5 ab	56.8 a	48.2 a
Guy wiring	38.2 a	37.0 ab	59.3 a	50.6 ab	63.0 a	46.9 a
Root barrier	32.1	38.3 ab	44.5	54.4 ab	53.1 a	56.8 a
S. macrantha						
Free growth	14.8bc	21.0 bc	25.9 cd	45.7 bc	46.9 a	44.4 a
Guy wiring	2.5 c	24.7 bc	32.1 bcd	38.2 bc	51.9 a	45.7 a
Root barrier	17.3bc	37.0 ab	50.6 ab	67.9 a	61.8 a	55.8 a
S. sesban						
Free growth	8.3 c	12.3 c	21.0 d	29.6	33.3 a	39.5 a
Guy wiring	8.6 c	18.5 bc	25.7 cd	40.7 bc	33.3 a	38.3 a
Root barrier	8.6 c	8.9 c	21.0 d	40.7 bc	42.0 a	34.5 a

Means in the same column followed by the same letter (s) are not significantly different at P = 0.05, according to Duncan's multiple range test.

All treatments produced no effect on number of plants per row, because the germination percentage was 100 % (Table 3).This indicates that seed germination and initial development of maize were not affected by the associated trees. The stover yield/row declined slightly with less tree competition (Fig. 2).The free growth of *S. macrantha* resulted in lower stover yield in the first four rows compared to the other treatments (Fig. 2).The effect of other treatments was pronounced only in the first two rows.

There were no significant differences in the number of cobs per row between the different treatment combinations. The effect of trees on number of cobs per row was confined to the first and second rows of the free growth of *S. sesban* (Table.4).This suggests that the number of cobs/row is not sensitive to the presence of trees.

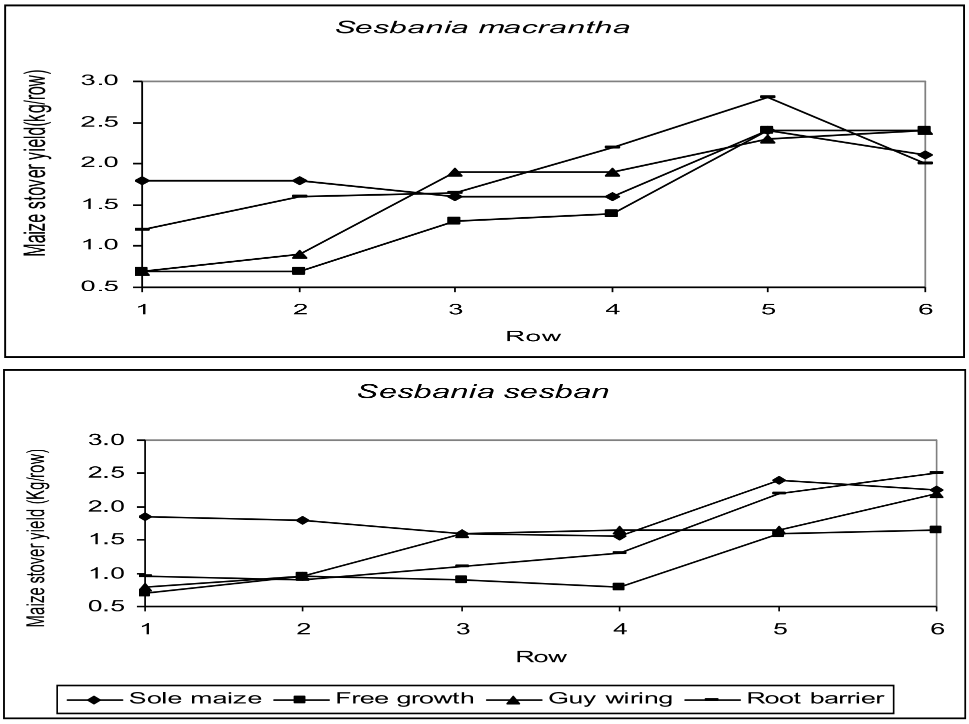


Figure 2. Effect of treatments on maize stover yield (kg/row) in sesbania/maize agroforestry system

Table 3. Effect of treatments on number of maize plants per row

Treatment	Row number					
	1	2	3	4	5	6
Sole maize	20.3	20.0	18.0	19.7	20.0	19.7
S. goetzei						
Free growth	19.7	19.3	20.3	21.0	20.3	21.0
Guy wiring	20.3	20.0	20.0	20.7	21.0	18.7
Root barrier	20.6	20.7	20.3	20.3	21.0	20.7
S. macrantha						
Free growth	20.3	20.3	21.0	20.3	21.0	19.3
Guy wiring	19.0	20.3	20.0	20.0	19.7	20.3
Root barrier	19.0	20.0	21.0	20.3	20.3	20.3
S. sesban						
Free growth	19.0	19.0	20.7	21.0	21.0	20.7
Guy wiring	19.6	18.7	21.0	20.0	20.0	20.3
Root barrier	20.0	19.3	20.2	20.3	20.0	20.3
LSD (0.05)	2.04	1.51	2.09	1.53	1.9	1.27

Table 4. Effect of treatments on number of maize cobs per row

Treatment	Row number					
	1	2	3	4	5	6
Sole maize	18.7	18.7	17.0	18.0	20.3	21.1
S. goetzei						
Free growth	19.7	20.7	20.3	22.7	20.3	21.0
Guy wiring	20.3	20.3	18.7	20.7	21.7	19.7
Root barrier	23.0	21.3	20.0	22.7	22.7	21.3
S. macrantha						
Free growth	16.0	18.3	19.3	21.3	20.3	19.0
Guy wiring	17.0	19.3	19.0	19.3	20.0	20.0
Root barrier	16.0	19.7	21.7	22.0	23.7	20.3
S. sesban						
Free growth	13.6	16.7	20.3	19.3	21.0	18.7
Guy wiring	16.3	17.0	19.7	18.3	18.7	18.7
Root barrier	16.3	18.3	19.3	20.7	19.7	20.0

The above findings indicated that maize grain yield per row is sensitive to competition from adjacent trees. This is manifested in decreased grain yield in the rows closer to the trees. The decrease amounted to 65% in the free growth, 49% in tree guy wiring and 41% in root barrier of *S. macrantha* as compared to sole maize. Similar results were obtained with *S. sesban* with reductions of 69%, 44% and 59% in free growth, guy wiring and root barrier treatment, respectively. These results agree with those of Salzar *et al,* (1993) in an alley cropping system of three leguminous trees and rice where rice yield was reduced in rows closer to the trees. However, *S. goetzei* did not show any clear trend compared to other species. The treatment combinations involving *S. sesban* resulted in significantly ($P \leq 0.05$) lower maize grain yield in all rows compared to sole maize (Fig 3).The free growth treatments produced the lowest grain yield in the first four rows indicating above and below ground competition effects.

Free growth of *S. macrantha* resulted in significantly ($P \leq 0.05$) lower yield in the first three rows, while the root barrier treatment produced higher grain yield in rows 2 to 5 (Fig. 3). The effect of *S. macrantha* extended up to the third row, indicating that both above and below ground competition had reduced grain yield of maize. However, root competition seems to contribute more to the reduction of grain yield than the above ground competition due to shading. Compared to sole maize, the average reduction in grain yield by *S. macrantha* was 56% in the first row. In the second row, the free growth and guy wiring reduced grain yield by 50% and 36%, respectively. In the third row, the free growth of *S. macrantha* reduced grain yield by 36% compared to sole maize. This result confirms that the effect of *S. macrantha* on maize yield was mainly due to below ground competition rather than to above ground competition. Root barrier eliminated the effect of competition.

S. sesban treatments resulted in lower grain yield ($P \leq 0.05$), in all rows, than sole maize (Fig. 3). Free growth treatment resulted in the lowest grain yield in the first four rows. This indicates that above and below ground competition reduced grain yield of maize by up to 65% in the first row and by up to 55% in the second row compared to sole maize. In the third and fourth rows, free growth and guy wiring reduced grain yield by 43% and 32%, respectively, and by 43% in the fifth row compared to sole maize. There was no effect on yield of the sixth row. The effect of *S. sesban* on maize grain yield seems to be due to below ground competition, because the effect of its shade did not exceed the third row, and reduction in yield extended up to the fifth row. These results show that below ground competition for water and nutrients from *S. macrantha* and *S. sesban* was much more than for above ground competition.

The percentage of light intercepted by *Sesbania* species and maize was significantly ($P \leq 0.05$) different between treatments.There was no clear trend in light interception by *S. goetzei* and maize, due to the lack of uniformity in their canopies (Fig. 4). The root barrier treatment of *S. macrantha* intercepted more light than the other treatments throughout the season, resulting in higher grain yield. This suggests that the reduction in maize yield was mainly due to root competition.

S. sesban free growth and root barrier treatments intercepted more light compared to guy wiring and sole maize (Fig. 4). This also indicates that root competition of *S. sesban* contributed more to crop yield reduction than above ground competition.

There were significant ($P \leq 0.05$, 0.01) differences in light interception (Table 5).The effect of *S. macrantha* and *S. sesban* on light interception at different distances from the trees was significant ($P \leq 0.05$). Throughout the measuring period, free growth and root barrier treatments of these two species intercepted significantly ($P \leq 0.05$) more light in the first three rows than in rows 4, 5 and 6.

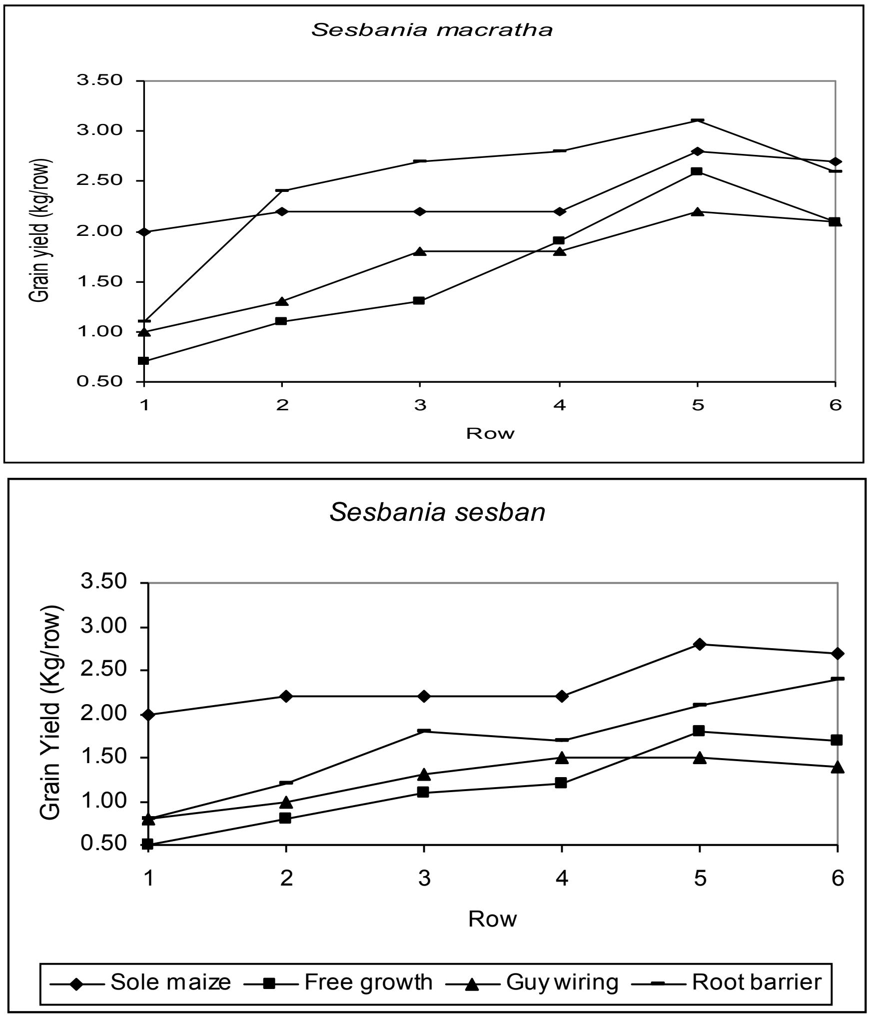


Figure 3. Effect of treatments on maize grain yield (kg/row) in a sesbania/maize agroforestry system

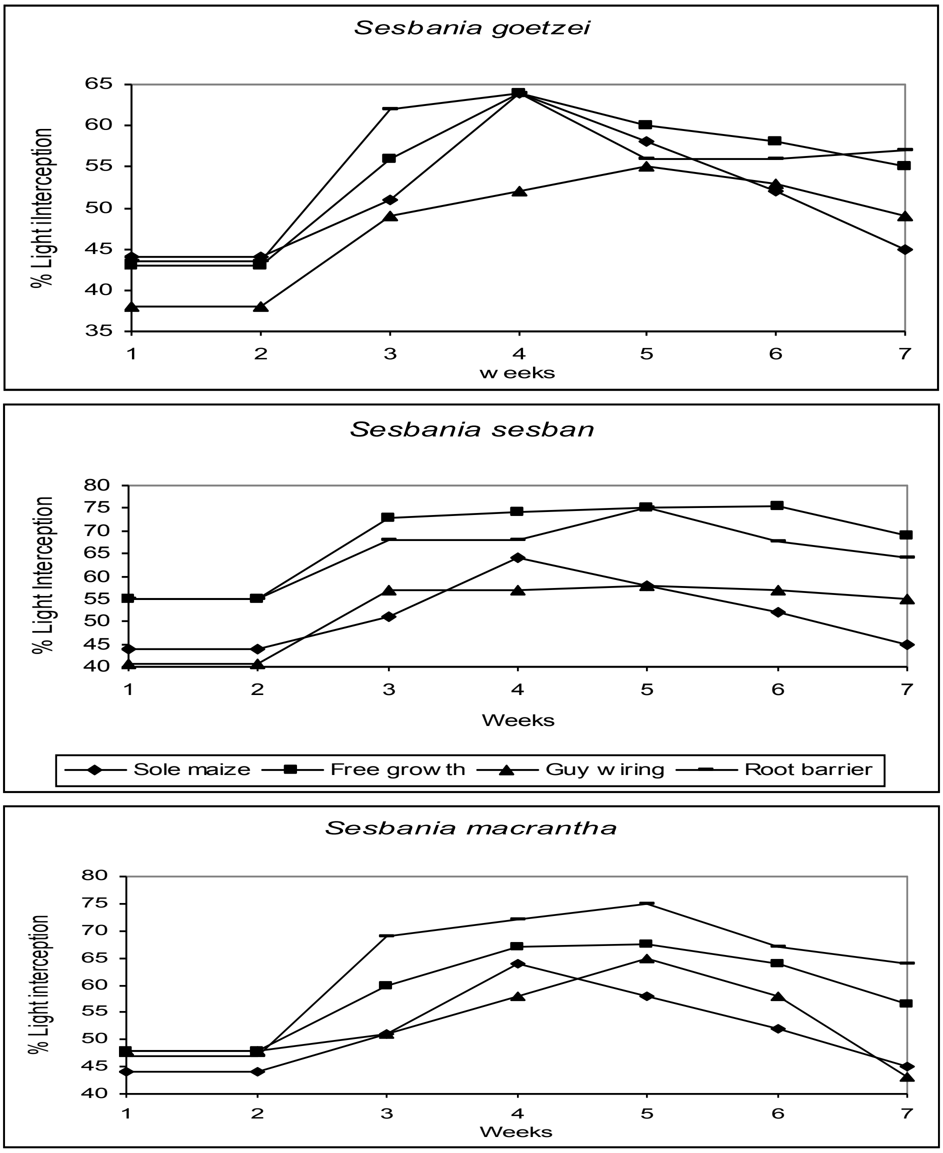


Figure 4. Effect of different treatments on percentage light interception by sesbanias and maize

S. goetzei and *S. macrantha* treatments had no effect on the average cobs weight/plot compared to sole maize (Table 6).On the other hand, *S. sesban* free growth and guy wiring treatments resulted in lower cobs weight per plot, indicting the negative effect of the roots of this species on maize compared to the other two species. These results show that competition did not affect cobs initiation, but it affected the translocation of assimilates to the cobs hence resulting in less cobs weight. Yamoah (1991) found similar results in a bean and sesbania hedgerow intercropping, where the cob weight was significantly decreased by competition, while the number was not.

Average grain yield/plot was significantly lower in *S. sesban* treatments compared to *S. macrantha* (guy wiring and free growth) and *S. goetzei* treatments (Table 6). However, average stover yield/plot was affected in all treatments, although Salzar *et al.* (1993) observed that rice biomass increased with distance from trees.

Table 5. Effect of treatments on percentage light interception by sesbanias and maize four weeks after sowing

Treatment	Row number					
	1	2	3	4	5	6
Sole maize	21.6a	27.1 a	19.1 a	13.3 b	17.5 b	31.0 a
S. goetzei						
Free growth	32.1a	27.6ac	22.9 a	28.6 ad	30.3 a	19.1 cb
Guy wiring	36.8a	22.2bc	25.5acd	22.2 bcd	26.6ace	22.7 bcd
Root barrier	27.3a	22.3 a	23.4 a	22.2 a	24.8 a	8.8 b
S.macrantha						
Free growth	33.9 a	43.9 a	37.0 a	14.4 b	17.7bc	27.8 ac
Guy wiring	56.1 a	19.7 b	17.1 b	19.2 b	23.0 b	19.9 b
Root barrier	40.4 a	45.6 a	35.1 ac	22.1 b	22.7 b	24.9 bc
S. sesban						
Free growth	39.5 a	48.6ac	53.5 bc	26.5 d	19.5 d	15.6 d
Guy wiring	60.9 a	15.7 b	13.9 b	23.2 b	17.9	17.1 b
Root barrier	41.9 a	45.6 a	36.7 a	17.1 b	19.4 b	22.4 b

Means in the same row followed by the same letter (s) do not differ significantly ($P \leq 0.05$), using Duncan's multiple range test.

Table 6. Effect of treatments on average cobs, grain and stover yield (kg/plot)

Treatment	Cobs weight	Grain yield	Stover yield
Sole maize	20.4 ± 0.49	14.4 ± 0.67	11.3 ± 0.05
S. goetzei			
Free growth	21.5 ± 0.29	15.1 ± 0.47	10.7 ± 0.05
Guy wiring	21.2 ± 0.42	14.6 ± 0.03	10.4 ± 0.03
Root barrier	22.8 ± 0.42	15.1 ± 0.05	11.4 ± 0.07
S. macrantha			
Free growth	15.6 ± 0.53	10.5 ± 0.06	8.8 ± 0.08
Guy wiring	15.0 ± 0.56	10.9 ± 0.06	10.1 ± 0.08
Root barrier	22.8 ± 0.69	15.0 ± 0.06	11.8 ± 0.06
S. sesban			
Free growth	12.0 ± 0.80	8.1 ± 0.05	6.7 ± 0.05
Guy wiring	11.4 ± 0.63	8.2 ± 0.04	8.9 ± 0.07
Root barrier	16.2 ± 0.63	10.8 ± 0.06	8.8 ± 0.07
LSD (0.05)	1.54		0.37

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التنافس على الموارد فوق و تحت سطح الأرض في نظام تشجير زراعي من أشجار السيسبانيا و الذرة الشامية

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موجز البحث: أجريت هذه الدراسة بمحطة ابحاث المركز الدولي لأبحاث التشجير الزراعي بمشاكوس، كينيا. لتحديد الأهمية النسبية للتنافس فوق وتحت سطح الأرض بين ثلاثة أنواع من أشجار السيسبانيا (*Sesbania sesban* و *Sesbania macrantha* و*Sesbania geotzei*) والذرة الشامية (*Zea mays).* لفصل التنافس فوق وتحت سطح الأرض. استخدم السلك النملي و مانع الجذور لإزالة تنافس الظل و الجذور على التوالي لكل نوع من السيسبانيا. كما تركت الأشجار لتنمو طبيعياً دون ازالة الجذور و الظل. كما استخدمت الذرة الشامية منفرده كشاهد. نظمت المعاملات في تصميم القطاعات العشوائية بثلاثة مكرارات. زرعت الذرة الشامية بين صفوف الأشجار بمعدل صف من الأشجار وسبعة صفوف من الذرة الشامية. تم قياس طول ومكونات إنتاجية الذرة الشامية وكمية الضوء الممتص بواسطة الأشجار و الذرة الشامية لأربعة أشهر. أثبتت النتائج أن *S. sesban* و *S. macrantha*لهما تأثير سلبي على نمو وانتاجية الذرة الشامية , وأزداد طول الذرة الشامية وإنتاجيتها مع زيادة المسافة من الأشجار.