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# Pruning effects on root distribution and nutrient dynamics in an acacia hedgerow planting in northern Kenya

I. PETER and J. LEHMANN*
*Institute of Soil Science and Soil Geography, University of Bayreuth, 95440 Bayreuth, Germany*
*(*Author for correspondence, E-mail: johannes.lehmann@uni-bayreuth.de)*

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**Abstract.** Tree pruning is a common management practice in agroforestry for mulching and reducing competition between the annual and perennial crop. The below-ground effects of pruning, however, are poorly understood. Therefore, nutrient dynamics and root distribution were assessed in hedgerow plantings of *Acacia saligna* (Labill.) H.L. Wendl. after tree pruning. Pruning to a height of 1.5 m was carried out in March and September 1996. In July and October 1996, the fine root distribution (< 2 mm) and their carbohydrate contents were determined at three distances to the tree row by soil coring. At the same time, foliar nutrient contents were assessed, whereas nutrient leaching was measured continuously. The highest root length density (RLD) was always found in the topsoil (0–0.15 m) directly under the hedgerow (0–0.25 m distance to trees). Pruning diminished the RLD in the acacia plots at all depths and positions. The relative vertical distribution of total roots did not differ between trees with or without pruning, but live root abundance in the subsoil was comparatively lower when trees were pruned than without pruning. In the dry season, the proportion of dead roots of pruned acacias was higher than of unpruned ones, while the fine roots of unpruned trees contained more glucose than those of pruned trees. Pruning effectively reduced root development and may decrease potential below-ground competition with intercropped plants, but the reduction in subsoil roots also increased the danger of nutrient losses by leaching. Leaching losses of such mobile nutrients as $NO_3^-$ were likely to occur especially in the alley between pruned hedgerows and tended to be higher after pruning. The reduced size of the root system of pruned acacias negatively affected their P and Mn nutrition. Pruning also reduced the function of the trees as a safety net against the leaching of nutrients for both $NO_3^-$ and Mn, though not for other studied elements. If nutrient capture is an important aim of an agroforestry system, the concept of alley cropping with pruning should be revised for a more efficient nutrient recycling in the system described here.

## Introduction

A major problem of simultaneous agroforestry systems is the competition between annual and perennial crops (Sanchez, 1995). Especially in alley cropping systems crop yields decline with decreasing distance to the tree row (Haggar and Beer, 1993; Matta-Machado and Jordan, 1995). This reduction can be a result of above-ground competition for light or below-ground competition for water and nutrients (Heinemann et al., 1997). In order to estimate the effects of below-ground competition it is important to know the root distribution (Schroth, 1995). Still very little is known about these tree-crop interactions in simultaneous agroforestry systems (Rao et al., 1998).

To optimize the production of an alley-cropping system the trees and associated crops should use different resources. Cannell et al. (1996) formulated the central agroforestry hypothesis that ‘the tree must acquire resources that the crop would otherwise not acquire’. A complementary root distribution between crop and tree is desirable to a certain degree in alley cropping. In semi-arid India, Singh et al. (1989) found an increase in growth and yield of cowpea, sorghum and castor when a polyethylene root barrier was installed between the root systems of the crop and *Leucaena leucocephala* (Lam.) de Wit. This indicates that a spatial separation of the root systems could be of advantage for the crop due to improved uptake of water and nutrients by the crop plants. Therefore, it is desirable to influence the tree root system in a way which reduces the lateral extension of tree root systems and increases the vertical growth.

If below-ground competition is minimized, the positive effects of tree roots e.g. the function as a safety-net for nutrients may be affected as well. The desired tree properties need to be optimized while the negative effects of competition should be minimized to an extent which allows the most efficient use of resources.

The root competitiveness of trees can be influenced by management. One possibility is shoot pruning, which is normally carried out in simultaneous systems to reduce competition for light and to supply the agroforestry system with green manure. However, pruning also has an effect on the root system (Fownes and Anderson, 1991). On the one hand the tree root system was reported to be more shallow after pruning (van Noordwijk and Purnomosidhi, 1995) but on the other hand to grow deeper when pruned and intercropped (Lehmann et al., 1998b). The influence of shoot pruning on soil nutrient dynamics has not been investigated up to now.

In this paper, we examine the effects of tree pruning on (i) root distribution, (ii) nutrition of trees and (iii) nutrient losses by leaching in hedgerow planting systems of *Acacia saligna* (Labill.) H.L. Wendl. with runoff irrigation in northern Kenya. This trial is part of a larger experiment on runoff agroforestry, and only the effects of pruning in acacia monocultures are presented here.

## Materials and methods

### *Study site*

The study was carried out in a dry tropical savanna near Kakuma in Northern Kenya (34°51′ East and 3°43′ North, altitude 620 m a.s.l.). The rainfall distribution is bimodal with a maximum during April–May and in September–October with a mean annual precipitation of 318 mm (from 14 years; W. I. Powell, and Turkana Drought Control Unit, unpublished data), 330 mm during the experimental year. Soils are classified as *Calcareous Fluvisols* (FAO, 1990); they are deep and loamy, with high pH (8.6–9.2) and EC (0.05–1.36 S $m^{-1}$) and low organic C (2.3–8.0 g $kg^{-1}$) and N (0.3 g $kg^{-1}$) contents. N, Zn, Mg and Ca were described as growth limiting nutrients for *Sorghum bicolor* (L.) Moench at this site (F. von Willert, unpublished data).

### *Experimental design and treatments*

Prior to this study, a runoff irrigation system was built in 1994 using a design of leveled basins, which ensured adequate water supply despite the dry climatic conditions (Lehmann et al., 1998a). Four basins were laid out in the contour and runoff water originating from a nearby mountain range was guided into the irrigation system. The basins could be filled in April and August/September 1996 up to a level of about 500 mm. The water infiltrated into the soil within one to two weeks. After the November rains in 1994, an alley-cropping system was planted with *Acacia saligna* laying out alleys 4 m wide with 1 m distance between trees within the row (2500 trees $ha^{-1}$). Each treatment with pruned or unpruned trees, was randomly arranged in the basins. In 1996, the fourth basin was flooded more often than the other ones; thus, only three replications could be used in this study. In March and September 1996, the trees were pruned to a height of 1.5 m and the whole biomass was taken out of the system.

### *Root sampling*

Root sampling was carried out in July and in October 1996. The root distribution was determined by destructive sampling at 0–0.15, 15–30, 0.30–0.60, 0.60–0.90, 0.90–1.20 and 1.20–1.50 m depth. Five samples were randomly taken within 0–0.25, 0.25–0.75 and 0.75–2.00 m distances from the hedgerow. The three ranges were chosen instead of specific distances to allow the calculation of root length density (RLD) per unit area for the whole cropping system. The samples were washed and only fine roots (diameter < 2 mm) were sampled. Live and dead roots were separated as described by Lehmann and Zech (1998). The root length density was then determined with the line-intersect method according to Tennant (1975).

### *Determination of carbohydrates*

Live and dead roots sampled in October 1996 were used for the determination of monosaccharides. Due to the limited root material we distinguished only between top- and subsoil. The roots from 0–0.30 m depth were combined to one sample as well as the roots from 0.60–1.50 m depth. Only roots under the tree row and in the center of the alley were analyzed. After they had been ovendried at 40 °C for 48 h and ground, 5–15 mg roots were hydrolyzed with 4 M trifluoracetic acid at 100 °C for four hours. The monosaccharides were purified using charcoal and Dowex 50 resin, and measured with an HP 5890 gas chromatograph using a DB-5 fused column and a FID detector. The carbohydrates were separately analyzed for uronic acids, such as glucuronic acid and galacturon acid, pentose- and hexose-sugars. The group of hexoses contains the monomers glucose, fructose, xylose and arabinose.

### *Plant nutrient analysis*

In order to characterize plant nutrition, the youngest fully developed acacia leaves were sampled in November 1996 after the second pruning (September 1996) when the trees had again a well developed tree top. The leaves were gently rinsed with deionised water to remove adhering particles and dried at 80 °C for 48 hours. Afterwards, they were finely ground with a ball mill.

C, N and S were determined after dry combustion with an automatic C/N/S Analyzer (Elementar). For the characterization of other nutrients, 200 mg dry leaves were digested in 2 mL concentrated $HNO_3$ at 105 °C for four hours. K, Ca, Mg, Fe, Mn and Zn were analyzed with an atomic absorption spectrometer (Varian), P was measured colorimetrically according to the molybdenum blue method (Olsen and Sommers, 1982).

### *Soil nutrient analysis*

In July and November 1996 soil samples were taken in the tree row and in the alley of the pruned and unpruned tree plots. In order to determine the soil mineral N contents, six subsamples were obtained with a purkhauer auger from 0–0.15, 0.15–0.30, 0.30–0.60 and 0.60–0.90 m depth in the hedgerow and the alley and combined, respectively. The samples were put into a cool box and transported as soon as possible to a deep freezer. The frozen soil was sieved, 50 g were mixed with 100 mL of 1 N KCl and shaken for 10 min. The extract was filtered, treated with chloroform, frozen and transported to the laboratory. $NH_4^+$ and $NO_3^-$ were measured colorimetrically with a Rapid Flow Analyzer (Alpkem).

Nutrient leaching was determined by (i) measurements of the soil water suction and nutrient contents in the soil solution, and by (ii) resin cores. Ceramic suction cups were installed at 0.35 and 1.20 m depth. Vacuum was adjusted to the soil water tension measured by tensiometers at the same site (Lehmann et al., 1998b). Soil solution was extracted at weekly intervals until the soil dried up again. Thus, only during July to October, soil solution could be sampled; this was considered to adequately represent the mobile nutrients, as water suctions later in the year were too high to permit relevant water movement in the soil. $NO_3^-$ and $NH_4^+$ were analyzed spectroscopically with a Rapid Flow Analyzer (Alpkem), K, Ca and Mg with ICP-AES. The soil water movement was calculated from measurements of the soil water suction using tensiometers at 0.45 and 1.50 m depth and gypsum blocks at 0.10 m depth. The nutrient fluxes were calculated using the procedures and parameters described in Lehmann et al. (1999).

Resin cores were installed at 0.35 m depth to determine the amount of mineral nutrients leached from the topsoil (Lehmann et al., 1999). The resin cores were 0.12 m long. For the adsorption corpus 50 mL of a combined anion and cation exchange resin (Amberlite MB 20) were mixed with 200 mL of acid washed sand, filled into the cores and slightly compacted to receive similar bulk densities as the surrounding soil. A 20 mm extension at the bottom filled with acid washed sand ensured a good contact of the core with the soil. The three core sections (soil, resin-sand mixture, sand) were separated by ash-free filters, which decomposed rapidly after the insertion. Therefore, they did not influence the hydraulic properties.

The cores were inserted under the tree row and in the alley (2 m distance from the trees) of the pruned and unpruned tree monoculture. They were installed in August 1996 and removed after infiltration of the runoff-water at the end of October. The column of the resin-sand mixture was cut into three layers, 0–0.06, 0.06–0.08 and 0.08–0.10 m, in order to verify that no nutrients were lost by leaching and that no capillary rise contaminated the results. The total amount of each fraction was weighed, and a subsample was dried and analyzed after extraction with 1 N KCl as described above.

### *Statistical analysis*

All yield and nutrient data were compared by analyses of variance using a randomized complete block design (ANOVA of STATISTICA Version 5). The nutrient leaching values were compared using a completely randomized design of the logarithmic values due to missing data and inhomogeneity of variances. The effect of position (tree row or alley) was computed as a split plot design (Little and Hills, 1978). In case of significant effects, individual means were compared with a multiple comparison of means using the Tukey test, unless indicated otherwise.

## Results

### *Root distribution*

The maximum root length density (RLD) was always found in the topsoil (0–0.15 m) directly under the trees (0–0.25 m distance to the hedgerow). Pruning significantly diminished the RLD of the sole cropped acacia stands ($P < 0.05$). In July, the RLD declined to one half and in October to one third of the RLD of unpruned trees. This reduction could be seen at all depths and positions (Figures 1 and 2).

The roots of unpruned acacias were distributed more homogeneously in the whole cropping system than roots of pruned acacias. The total amount of roots per unit area decreased with increasing distance to the tree row to a lesser degree in the unpruned (in July 41%–29%–30%, in October 39%–33%–28% at 0–0.25, 0.25–0.75, 0.75–2 m distance) than in the pruned acacia stands (in

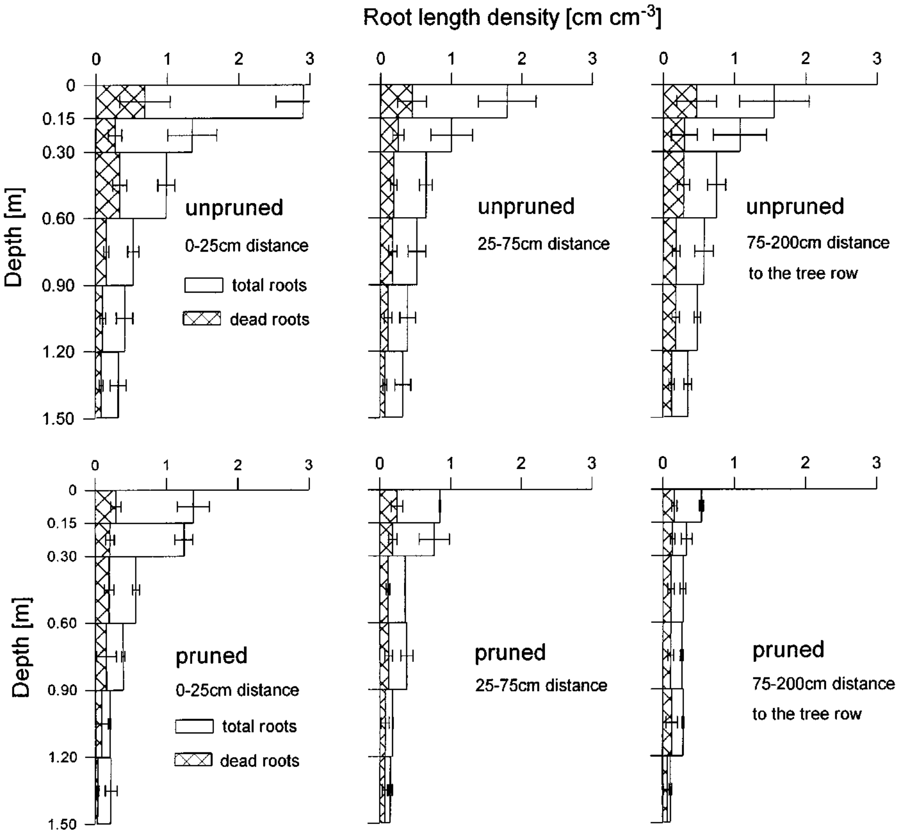

*Figure 1.* Root length density distribution of *Acacia saligna* at different distances to the hedgerow in northern Kenya in July 1996 ($n = 3$; means and standard errors).

July 46%–32%–22%, in October 44%–32%–24%). The distribution with depth, however, did not differ between trees with or without shoot pruning ($P > 0.05$). About 50% of the total RLD of the root systems was always found in the top 0.3 m of the soil.

In the alley of the pruned acacias, the RLD was only 38% of the RLD of the unpruned trees in July. After the second pruning and the dry season in October this reduction of RLD was even greater, with RLD in the alley of pruned treatments being only 30% of the RLD of unpruned trees. The decline of the total RLD (dead and live roots) after shoot pruning was similar in both the top- and subsoil. The live root density, however, showed a stronger reduction in the subsoil (33%) than in the topsoil (62%) due to the shoot pruning in July.

After the second pruning the ratio of live-to-dead roots was significantly lower ($P < 0.05$) in the pruned treatment than the unpruned one. Additionally, the pruned acacias showed a larger decrease in the ratio with increasing

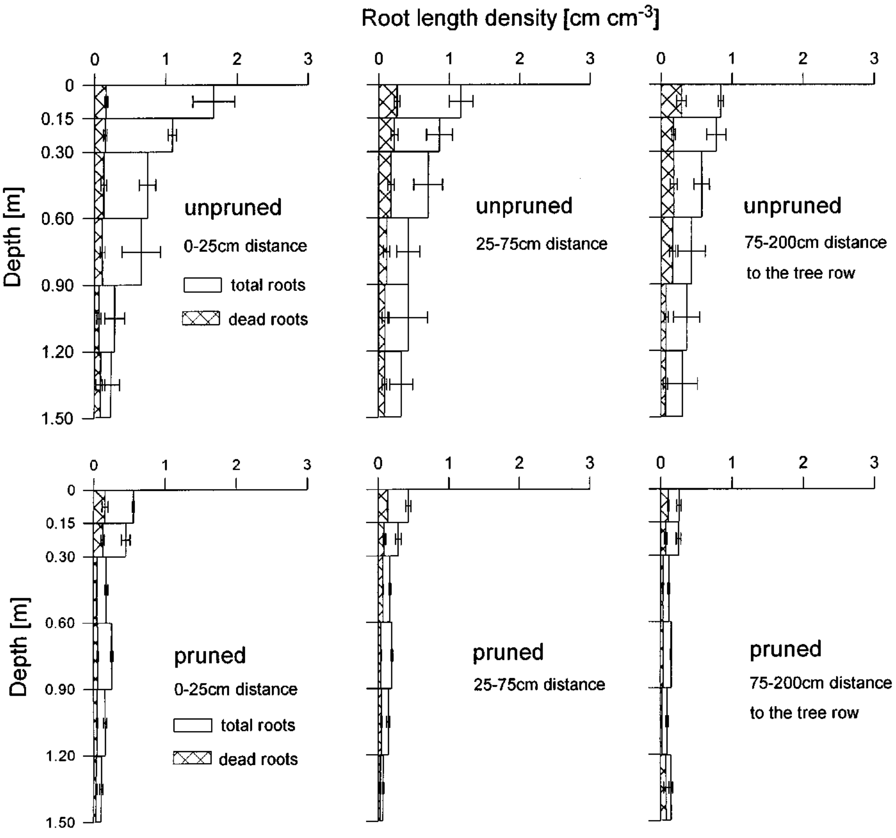

*Figure 2.* Root length density distribution of *Acacia saligna* at different distances to the hedgerow in northern Kenya in October 1996 ($n$ = 3; means and standard errors).

distance to the trees than the unpruned trees being in pruned treatments 3.1 and 2.5 directly under the trees and 1.6 and 1.8 in the middle of the alley in July and October, respectively. Without tree pruning, the ratio of live-to-dead roots was 3.0 under the tree row and 2.1 in the alley in July, and 4.0 and 3.6 in October.

### *Carbohydrate contents of fine roots*

The glucose and fructose concentration was significantly higher ($P < 0.05$) in fine roots of unpruned trees than in pruned trees (Tables 1 and 2). The contents of arabinose were significantly ($P < 0.05$) higher in live roots than in dead roots. Roots from the topsoil possessed a significantly ($P < 0.05$) higher concentration of fructose than roots from the subsoil. A significant interaction between treatment and depth ($P < 0.05$) was calculated for the sum of neutral sugars, the sum of uronic acids and for the total amount of all sugars:

*Table 1.* Carbohydrate contents in live fine roots (< 2 mm) of *Acacia saligna* at different horizontal and vertical distances from the hedgerow in pruned and unpruned stands in northern Kenya.

| Treatment | Depth [m] | Xylose | Arabinose | Fructose | Glucose | Hexoses | Pentoses | Uronic acids | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | [mg g$^{-1}$ C] | | | | | | | |
| Tp[1]/A[2] | 0–0.3 | 179.0 | 55.9 | 1.1 | 30.6 | 266.6 | 43.7 | 18.5 | 328.8 |
| | | (±28.4) | (±20.7) | (±1.0) | (±21.3) | (±33.6) | (±4.1) | (±3.2) | (±39.2) |
| | 0.6–1.5 | 104.9 | 44.3 | 0.6 | 13.5 | 163.3 | 33.6 | 9.9 | 206.1 |
| | | (±34.1) | (±7.4) | (±1.1) | (±2.3) | (±34.0) | (±5.0) | (±1.4) | (±34.8) |
| Tp/H | 0–0.3 | 124.4 | 58.9 | 1.3 | 26.3 | 210.9 | 62.1 | 20.0 | 292.1 |
| | | (±31.9) | (±8.1) | (±1.2) | (±6.6) | (±27.3) | (±12.7) | (±2.3) | (±22.8) |
| | 0.6–1.5 | 129.7 | 60.2 | 0.5 | 20.7 | 211.1 | 45.9 | 12.2 | 276.2 |
| | | (±44.6) | (±19.2) | (±0.9) | (±11.9) | (±44.3) | (±8.1) | (±5.9) | (±33.2) |
| Tn/A | 0–0.3 | 109.1 | 57.7 | 1.8 | 25.5 | 194.1 | 53.0 | 18.5 | 265.5 |
| | | (±45.2) | (±30.5) | (±0.7) | (±8.8) | (±68.5) | (±22.2) | (±8.2) | (±97.7) |
| | 0.6–1.5 | 120.1 | 54.7 | 2.3 | 23.5 | 200.6 | 48.1 | 21.5 | 275.8 |
| | | (±37.2) | (±2.3) | (±0.5) | (±6.7) | (±41.5) | (±3.6) | (±7.4) | (±52.8) |
| Tn/H | 0–0.3 | 100.9 | 58.4 | 1.2 | 29.9 | 190.4 | 53.6 | 17.0 | 258.8 |
| | | (±48.4) | (±17.5) | (±0.4) | (±18.7) | (±81.1) | (±17.5) | (±4.6) | (±101.9) |
| | 0.6–1.5 | 118.8 | 56.7 | 1.1 | 31.0 | 207.6 | 49.1 | 16.6 | 265.5 |
| | | (±35.6) | (±27.5) | (±1.0) | (±12.8) | (±48.5) | (±19.2) | (±7.3) | (±77.8) |

[1] Tp = pruned; Tn = unpruned trees.

[2] A at 0.75–2.0 m; H at 0–0.25 m distance to the hedgerow.

Means and standard errors ($n = 3$).

*Table 2.* Carbohydrate contents in dead fine roots (< 2 mm) of *Acacia saligna* at different horizontal and vertical distances from the hedgerow in pruned and unpruned stands in northern Kenya.

| Treatment | Depth [m] | Xylose | Arabinose | Fructose | Glucose | Hexoses | Pentoses | Uronic acids | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | [mg $g^{-1}$ C] | | | | | | | |
| Tp[1]/A[2] | 0–0.3 | 116.2 | 42.8 | 0.4 | 16.4 | 175.8 | 38.4 | 10.4 | 232.2 |
| | | (±86.1) | (±14.7) | (±0.8) | (±11.1) | (±101.3) | (±24.0) | (±4.3) | (±108.6) |
| | 0.6–1.5 | 33.3 | 31.9 | 0.0 | 17.3 | 82.4 | 23.2 | 8.1 | 122.0 |
| | | (±25.8) | (±26.2) | (±0.0) | (±15.6) | (±50.1) | (±6.5) | (±4.8) | (±62.9) |
| Tp/H | 0–0.3 | 138.8 | 56.4 | 1.4 | 29.1 | 225.6 | 62.1 | 18.0 | 304.1 |
| | | (±42.0) | (±7.8) | (±1.4) | (±5.9) | (±51.9) | (±8.3) | (±4.9) | (±54.3) |
| | 0.6–1.5 | 96.4 | 46.6 | 0.6 | 19.3 | 162.9 | 41.1 | 13.6 | 210.8 |
| | | (±58.0) | (±22.0) | (±1.1) | (±9.8) | (±67.0) | (±17.1) | (±4.6) | (±78.0) |
| Tn/A | 0–0.3 | 78.4 | 43.3 | 1.3 | 15.3 | 138.2 | 37.9 | 14.4 | 192.5 |
| | | (±63.1) | (±41.1) | (±1.3) | (±13.6) | (±140.2) | (±30.3) | (±15.4) | (±136.0) |
| | 0.6–1.5 | 167.5 | 29.4 | 1.3 | 15.1 | 213.3 | 36.7 | 15.9 | 266.7 |
| | | (±147.3) | (±15.5) | (±1.2) | (±5.8) | (±157.0) | (±16.9) | (±4.2) | (±159.6) |
| Tn/H | 0–0.3 | 101.4 | 41.1 | 0.8 | 16.8 | 160.2 | 41.5 | 13.4 | 215.6 |
| | | (±80.6) | (±19.7) | (±0.8) | (±7.9) | (±103.7) | (±20.4) | (±7.8) | (±123.3) |
| | 0.6–1.5 | 128.9 | 51.3 | 0.5 | 37.4 | 218.1 | 38.4 | 13.2 | 269.7 |
| | | (±67.7) | (±11.7) | (±0.9) | (±28.5) | (±76.8) | (±17.7) | (±5.2) | (±96.7) |

[1] Tp = pruned; Tn = unpruned trees.

[2] A at 0.75–2.0 m; H at 0–0.25 m distance to the hedgerow.

Means and standard errors (*n* = 3).

in roots of pruned acacias the sugar content decreased with depth, whereas it increased in unpruned treatments. When the trees were pruned, the concentration of fructose was significantly ($P < 0.01$) lower in roots from the alley than in roots directly beneath the trees, which was not observed without tree pruning. In the subsoil, the sum of hexoses was significantly ($P < 0.05$) lower in dead roots of pruned trees than in dead roots of unpruned acacias.

### *Nutrient dynamics*

The results of the resin core measurements showed a great variation as seen from the standard errors (Table 3). Only the leaching of Mn at 0.35 m depth was significantly higher ($P < 0.05$) under pruned than unpruned trees. Beneath the tree row leaching of Na and Mn was reduced ($P < 0.05$) compared to the alley. A significant interaction between position and treatment was determined for Mn ($P < 0.05$).

The nutrient leaching rates, determined with the water balance and soil solution nutrient contents, were lower at 1.2 m than at 0.35 m depth (Table 2; significant at $P < 0.05$). In the subsoil at 1.2 m depth, a tendency was seen for higher $NO_3^-$ leaching in the alley than under the pruned hedges. Although tree pruning substantially increased $NO_3^-$ and K leaching, differences were not significant.

In the unpruned acacia plots, the mineral N contents decreased from the top- to the subsoil in July (Figure 3), but were uniformly distributed in the soil profile in October (Figure 4). After the second pruning in October, however, the subsoil $NO_3^-$ contents were significantly higher in the alley than under the tree row of the pruned acacia and both positions of the unpruned acacias ($P < 0.05$, significant interactions treatment × position and depth × treatment). In plots with unpruned trees the distribution of $NO_3^-$ was similar in the alley and under the trees.

The foliar P and Mn contents were significantly higher in unpruned than in pruned trees ($P < 0.05$; Table 4). The other nutrients were not significantly different with and without pruning.

## Discussion

### *Reaction of the root system to pruning*

The vertical distribution of *Acacia saligna* roots was within the range of results from other experiments (e.g. Jonsson et al., 1988; Toky and Bisht, 1992). As in the present study a reduction of the root length density following pruning was observed by Fownes and Anderson (1991) for *Sesbania sesban* (L.) Merr. and *Leucaena leucocephala*. In addition, Schroth and Zech (1995) reported lower root length densities when *Gliricidia sepium* (Jacq.) Walp. was pruned. However, van Noordwijk et al. (1991) showed that pruning of *Peltophorum*

*Table 3.* Amount of leached nutrients in pruned and unpruned *Acacia saligna* monoculture in northern Kenya during August to October 1996.

| Treatments | Depth (m) | $NO_3$ | $NH_4$ | P | K | Ca | Na | Mg | Mn |
|---|---|---|---|---|---|---|---|---|---|
| | | [kg ha$^{-1}$] | | | | | | | |
| Tp[1]A[2]/R[3] | 0.35 | 30.0 | 4.46 | 2.62 | 3.15 | 55.6 | 130.1 a | 7.07 | 0.43 a |
| | | (±11.2) | (±1.02) | (±0.47) | (±1.20) | (±21.4) | (±44.0) | (±2.64) | (±0.04) |
| TpA/S | | 54.9 a | –[4] | – | 42.9 a | 209.5 a | n.d. | 87.5 a | n.d. |
| | | (±46.97) | | | (±29.0) | (±118.1) | | (±51.2) | |
| TpH/R | | 26.3 | 4.43 | 2.34 | 2.71 | 138.4 | 40.2 b | 22.5 | 0.41 b |
| | | (±2.98) | (±0.35) | (±0.75) | (±1.21) | (±96.2) | (±8.5) | (±16.9) | (±0.13) |
| TpH/S | | 34.6 a | – | n.d.[5] | 62.6 a | 181.0 a | n.d. | 88.9 a | n.d. |
| | | (±30.1) | | | (±43.5) | (±111.3) | | (±50.7) | |
| TnA/R | | 17.8 | 7.02 | 2.85 | 1.87 | 83.6 | 60.9 a | 10.3 | 0.53 a |
| | | (±7.47) | (±1.79) | (±0.14) | (±0.59) | (±42.6) | (±35.2) | (±4.81) | (±0.08) |
| TnA/S | | 6.5 a | – | n.d. | 49.0 a | 175.8 a | n.d. | 110.0 a | n.d. |
| | | (±4.70) | | | (±28.6) | (±43.6) | | (±34.7) | |
| TnH/R | | 17.2 | 7.71 | 3.65 | 7.80 | 87.3 | 16.3 b | 10.6 | 0.27 b |
| | | (±14.1) | (±3.45) | (±0.42) | (±6.63) | (±69.7) | (±7.3) | (±7.4) | (±0.08) |
| TnH/S | | 12.2 a | – | n.d. | 43.1 a | 211.2 a | n.d. | 110.0 a | n.d. |
| | | (±3.40) | | | (±15.3) | (±22.5) | | (±39.0) | |
| TpA/S | 1.20 | 16.6 b | – | n.d. | 37.4 b | 54.0 b | n.d. | 24.4 b | n.d. |
| | | (±15.3) | | | (±17.7) | (±31.4) | | (±10.6) | |
| TpH/S | | 10.6 b | – | n.d. | 36.0 b | 26.3 b | n.d. | 23.2 b | n.d. |
| | | (±6.34) | | | (±15.7) | (±9.4) | | (±9.5) | |
| TnA/S | | 6.3 b | – | n.d. | 20.5 b | 39.2 b | n.d. | 45.8 b | n.d. |
| | | (±2.83) | | | (±4.31) | (±5.2) | | (±13.3) | |
| TnH/S | | 1.2 b | – | n.d. | 24.6 b | 101.5 b | n.d. | 77.0 b | n.d. |
| | | (±0.45) | | | (±15.2) | (±39.4) | | (±28.9) | |

[1] Tp = pruned; Tn = unpruned trees; [2] A at 0.75–2.0m. H at 0–0.25m distance to the hedgerow. [3] R determined with resin cores; S suction cups.
[4] Not detectable. [5] Not determined.
Values followed by the same letter within a row are not significantly different at $P < 0.05$ (means and standard errors; $n = 3$).

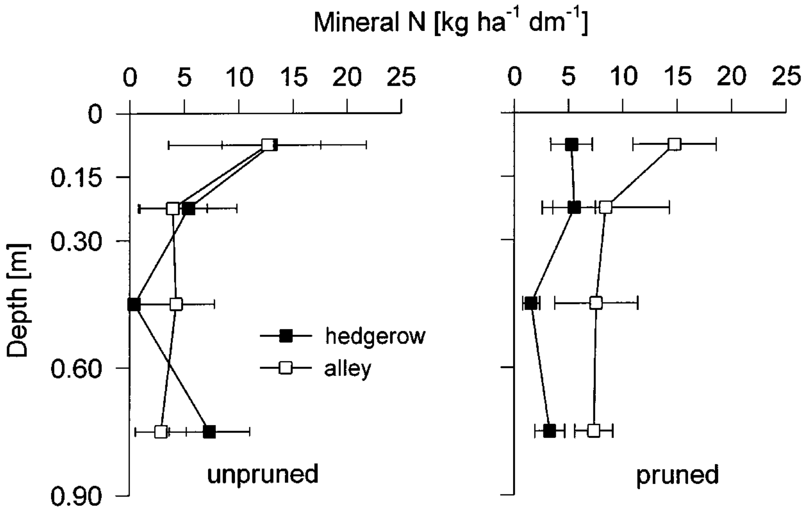

*Figure 3.* Distribution of soil mineral nitrogen in unpruned and pruned *Acacia saligna* in northern Kenya in July 1996 ($n$ = 3; means and standard errors).

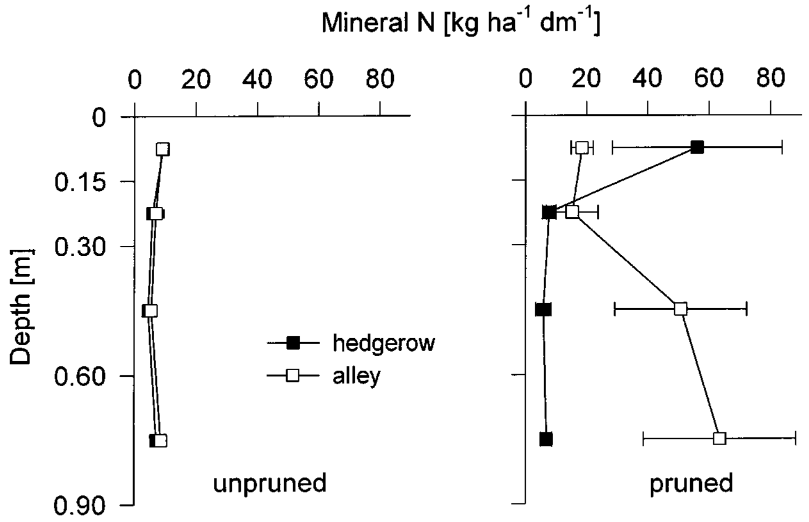

*Figure 4.* Distribution of soil mineral nitrogen in unpruned and pruned *Acacia saligna* in northern Kenya in October 1996 ($n$ = 3; means and standard errors).

*dasyrachis* Kurz led to a larger number of superficial roots of smaller diameter, while the shoot-to-root ratio remained constant. This was confirmed for *Paraserianthes falcataria* (L.) Nielsen, *Gliricidia sepium*, *Cassia siamea* Lam. and *Calliandra calothyrus* Meissn. (van Noordwijk and Purnomosidhi, 1995).

In our study the ratio of live-to-dead roots indicated that more roots were

*Table 4.* Foliar nutrient contents of pruned and unpruned *Acacia saligna* in northern Kenya in November 1996.

| Treatments | P | K | Ca | Na | N | Mg | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | [mg kg$^{-1}$] | | | | | | | | |
| Unpruned | 2.23* | 20.57 | 12.78 | 1.91 | 23.3 | 5.22 | 404.05 | 135.26* | 34.06 |
| *SE* | (±0.12) | (±2.65) | (±1.45) | (±0.09) | (±1.39) | (±0.66) | (±26.90) | (±33.43) | (±6.79) |
| Pruned | 2.05* | 34.41 | 12.23 | 3.52 | 21.7 | 4.78 | 497.50 | 87.05* | 43.37 |
| *SE* | (±0.14) | (±10.19) | (±1.79) | (±0.94) | (±2.12) | (±0.05) | (±107.82) | (±1.46) | (±10.58) |

* Significantly different in one column at $P < 0.05$ (means and standard errors; $n = 6$).

dying in the alley as an effect of shoot pruning than in the tree row. Pruning stressed the trees and affected the survival of fine roots in the outer acacia root system. This stress can be clearly demonstrated by the lower sugar contents in the live roots of the pruned acacias.

Pruning the acacia at a height of 1.5 m resulted in a removal of nearly all green leaves. This reduced the assimilation rate and consequently influenced the root system. Carbohydrates were initially retranslocated for the regrowth of the above-ground biomass or were respired. Several studies showed that the new formation of the tree top reduced the carbohydrate reserves in stem and roots (Kandiah et al., 1984; Eissenstatt and Duncan, 1992; Erdmann et al., 1993) and that regular pruning led to a transfer of assimilates from root to shoot biomass (Schroth and Zech, 1995). This processes of translocation and respiration of carbohydrates could be one factor controlling the equilibrium of the root-to-shoot ratio.

Consequently, areas with a large decrease of RLD after pruning corresponded with areas of low monosaccharid concentrations in the roots, especially in the subsoil and between the tree rows. Therefore, the retranslocation of sugars was more intense with further distance to the stem. This has important implications for the nutrient and water uptake. If more soil moisture is available at larger depths as shown for the studied system (Lehmann et al., 1998b), pruned trees will not be able to utilize this water as efficiently as unpruned trees. The same applies to soil nutrients, which will be discussed below.

### *Implications for tree-crop combinations*

The reduction of RLD after pruning indicated a low below-ground competitiveness of the pruned trees. This was confirmed by Lehmann et al. (1998b) who used the natural $^{13}$C abundance to distinguish between acacia and sorghum roots in a study at this site. In the tree+crop combination, roots of intercropped sorghum amounted to 48% of the total RLD directly beneath the pruned acacias. Therefore, the sorghum roots effectively utilized the topsoil under the pruned hedgerow (Lehmann et al., 1998b).

The more superficial root system, however, resulted in higher below-ground competition, since root zones of the tree and annual crop were less complementary than without tree pruning. But as the pruned acacias were less competitive than unpruned ones, the sorghum was able to force the acacia roots into the subsoil (Lehmann et al., 1998b). Therefore, complementarity could be achieved by reducing the competitiveness of the trees. Consequently, the annual crop was able to use more soil resources when the trees were pruned. Crop production was also shown to benefit from this shoot pruning (Droppelmann et al., 2000). With a sorghum intercrop, this was primarily an effect of reduced shading. However, even if the above-ground competition can be minimized by choosing different growth types or spacing for *Acacia saligna*, unpruned acacias will always exert pronounced below-ground competition.

### *Does pruning affect plant/soil nutrient dynamics?*

The pruned trees with their reduced root system could not take up as much P as unpruned trees with a more extensive root system. As P is an immobile nutrient, the soil solution normally contains very little P compared to other nutrients (Sposito, 1989). For that reason the uptake of P through mass flow is low and the P exploitation of plants is limited to the rhizosphere soil (Singer and Munns, 1996). For an efficient uptake of immobile nutrients a high root length density is the key requirement (van Noordwijk and Willigen, 1991). In this study, more mobile elements like $NO_3^-$ and $K^+$ were transported in sufficient amounts to the roots by the soil solution. Consequently, the foliar nutrient contents of these elements did not differ between pruned and unpruned trees.

The similar N-nutrition of pruned and unpruned acacias may indicate that root shedding after pruning had little effects on the $N_2$ fixation ability. Similar observations were made by Kadiata et al. (1998), who reported that tree pruning did not affect the percentage of $N_2$ fixation in *Leucaena* or *Gliricidia*.

Concerning the uptake of N and other mobile nutrients, it was feared that the RLD reduction would lead to a higher nutrient leaching due to a decreasing ability of the tree roots to act as a safety-net for nutrients. Soil mineral N contents indeed proved that the acacias were not able to efficiently utilize mineral N in the alley when the trees were pruned. This was especially obvious after the second pruning in October and would probably be more pronounced with further pruning. Moreover, the nutrient flux measurements indicated that increased leaching occurred for N and Mn as a result of tree pruning. For the other elements a higher leaching rate was not detected.

Subsoil nitrate accumulations have been reported in tropical cropping systems from several locations (e.g. Hartemink et al., 1996; Mekonnen et al., 1997). Woody legumes planted as improved fallows were able to recycle this N source as shown e.g. by Mekonnen et al. (1997) for *Sesbania sesban* in semiarid Kenya. For hedgerow trees this ability seems to be largely reduced, when they are pruned as in alley cropping.

In the hedgerow intercropping system studied at the same site, however, low N leaching was observed between the tree rows under alley cropped sorghum. This low N leaching was caused to a small extent by nutrient interception of the tree roots, but more so by the N uptake of the intercrop from the topsoil (Lehmann et al., 1999). In our study, unpruned trees could recycle subsoil nutrients which were susceptible to leaching much better than pruned trees, but at the same time reduced intercrop yields to an extent which made crop production not feasible as shown by Droppelmann et al. (2000). This result stresses the importance to rethink the concept of alley cropping with pruned hedges for the production of mulch material. If the prime goal of this management is to recycle nutrients from the subsoil and to improve nutrient availability at the topsoil, alley cropping is not efficient with the system studied here.

## Conclusions

Tree pruning strongly decreased the root length density by lowering the supply of assimilates from the leaves and retranslocating sugars to above-ground organs. Therefore, pruning the above-ground biomass was an effective way of controlling below-ground growth. This can be used in intercropping systems to manage tree-crop interactions. The lower root abundance and the laterally restricted root system after pruning will certainly decrease below-ground competition and have a positive effect on crop yields. But it also affects tree nutrition and soil nutrient fluxes. Thus, the reduction of the root system led to a lower uptake of immobile nutrients such as P. For the mobile $NO_3^-$ the risk of leaching in the alley increased after pruning. The acacias were only efficient in taking up nutrients from greater depths between the tree rows when they were not pruned. The decision to prune trees in hedgerow intercropping usually depends on more than just below-ground interactions. However, it is important to consider the effects of pruning on soil nutrient fluxes. Our results suggest the need to study the effects of different management options such as pruning separately for the tree and crop components in mixed cropping systems. Otherwise, it will not be possible to evaluate the changes induced by this management.

Pruning considerably reduced the ability of the trees to capture leached nutrients. It is therefore doubtful if hedgerow intercropping with tree pruning is as effective in recycling nutrients as it would be desirable for nutrient conservation. Especially at the onset of the rains, trees in alley cropping are frequently cut to mulch the leaves and open the canopy for optimal light penetration to improve crop growth. This is also the time when most of the soil nutrients are usually lost by leaching. A partial pruning of trees may offer an alternative as well as leaving some trees unpruned. Tree crops such as fruit trees should be tested in alley cropping in order to capture nutrients throughout the cropping season. Further studies are necessary to examine whether non-pruned tree crops can be identified and managed for hedgerow intercropping.

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