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Root architecture of provenances, seedlings and cuttings of *Melia volkensii*: implications for crop yield in dryland agroforestry

J.M. Mulatya[1], J. Wilson[2], C.K. Ong[3], J.D. Deans[2] and J.I. Sprent[4]

[1]Kenya Forestry Research Institute, P.O. Box 20412, Nairobi, Kenya

[2]Centre for Ecology and Hydrology, Edinburgh, Bush Estate, Penicuik, EH26 0QB, Scotland, U.K.

[3]International Centre for Research in Agroforestry, United Nations Avenue, P.O. Box 30677, Nairobi, Kenya

[4]University of Dundee, Millers' Wynd, Dundee, DD1 4HN, Scotland, U.K.

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Corresponding Author CK Ong

Tel. +254 2 521450; Fax. 254 2 521001; Email c.ong@cgnet.com

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Abstract

Melia volkensii (Gürke) is being increasingly promoted as an on-farm tree in Kenya. Researchers' and farmers' views on its competitiveness with crops differ; research station studies have found it to be highly competitive whereas farmers do not consider it to be so. Because of difficulties in seed germination, it is probable that dissemination programmes will rely upon plants produced from root and stem cuttings, rather than on seedlings. This study evaluates differences in root system architecture of plants raised from seed (of four provenances), stem or root cuttings and the relationships between the competitivity index (CI) and crop yield. Cuttings were more shallowly rooting than seedlings, and had higher competitivity indices, and there was a negative relationship between CI and crop yield. No differences in root architecture between provenances were found. Therefore, to reduce tree-crop competition, the use of seedlings rather than cuttings should be recommended when promoting the use of this species on dryland farms. If cuttings are used to circumvent the problems of seed germination, alternative methods of controlling competition, such as root pruning, need to be considered.

Introduction

Melia volkensii (Gürke) (melia) is a multipurpose dryland tree species commonly utilised by farmers in Kenya. The tree is considered to be deeply rooting [Stewart and Blomley, 1994] and many farmers believe that it does not compete with crops [Tedd, 1997]. However, in comparative trials, researchers found melia to be more competitive than numerous other tree species [Ong et al., 1999; Mulatya, 2000].

Although farmers are aware that shade cast by trees can depress crop yield, and they frequently prune branches to limit this, most farmers either have no concept of below ground competition or simply accept it as an inevitable consequence of combining trees and crops in farmland [Mulatya, 2000]. In contrast, researchers find that below ground competition is a major problem in simultaneous agroforestry systems and it has been the focus of much research in recent years [van Noordwijk et al., 1996].

Soil water is usually the main constraint to system productivity in drylands [Jackson and Wallace, 1999], hence root distribution is an important determinant of tree-crop competition, because it defines the locations of soil water that are accessible to plants. Where tree roots are shallow, they occupy the same soil layers as crops and competition for water between trees and crops is virtually unavoidable [Ong et al., 1999], leading to considerable reductions in crop yield.

The seeds of *M. volkensii* are difficult to germinate [Kidundo, 1997; Milimo, 1989; Stewart and Blomley, 1994], and a recent study [Mulatya, 2000] indicated that the majority (60%) of farmers in Kitui and Mbeere districts of Kenya who have this species on their farm, relied on natural regeneration of seedlings. Of the remainder, 34 % used transplanted saplings and the rest used either root cuttings or nursery raised seedlings, where these were available. However, reliance on natural regeneration is a major constraint to the expansion of use of this species as the low germination rate (< 5%) obtained by farmers [Stewart and Blomley, 1994] means that it is only an option where trees are already abundant. The use of alternative propagation methods may result in problems because melia trees originating from root cuttings are reported to be unstable [Stewart and Blomley, 1994]. Instability problems due to shallow rooting, have also been identified in rubber plantations established from cuttings [Carron and Enjarlic, 1983], and studies of other tree species indicate that both propagation method and transplanting can have long term effects on root architecture (depth of rooting and numbers of roots) which could alter the ways that trees compete with adjacent crops [Bell et al., 1993; Brutsch et al., 1977; Halter and Chanway, 1993; Khurana et al., 1997; Riedacker and Belgrand, 1983]. In Ong et al.'s, [1999] study, melia plants had been raised from root cuttings and consequently the discrepancy between researchers' findings of strong competition and farmers' views that the species is not competitive, may arise from the difference in the planting material used (cuttings *vs*. seedlings). A further consideration is that provenances may vary in their competitive effects, through physiological or root architecture variation.

Melia is an important indigenous tree species. It provides farmers with valuable termite-resistant timber, firewood and fodder. A recent survey of farmers in dry-zone Mbeere, Kenya, indicated that it was their most preferred tree for animal fodder [Roothaert and Franzel, 2001] and the majority of farmers in Mbeere and Kitui consider that it provides the best timber which is locally available, and favour it to exotics [Mulatya, 2000]. Melia is being targeted by the Kenya Forestry Research Institute as a priority species for dryland farming, and it is important to understand the causes of differences between farmers' and scientists' perceptions of competition, as considerations of planting stock type or provenance may need to be built in to research and germplasm and information dissemination programmes.

The objectives of this study were: to determine whether root architecture of young trees was influenced by the method of propagation (seedling, stem or root cuttings), and whether root architecture of seedlings was influenced by provenance; to evaluate some parameters of root architecture on older trees in farmers' fields; and to determine the relationship between root architecture and crop yield in both farmers' fields and research station studies.

Materials and Methods.

Study sites

Research station studies were conducted at ICRAF's field station at Machakos, Kenya (1° 33'S and 37° 8'E) at a mean elevation of 1660 m. The bimodal rainfall averages 740 mm per annum. Soils are well-drained dark brown sandy clays, derived from basement complex gneiss. They are classified as Haplic Lixisols (FAO-UNESCO) or Kandic Rhodulstalfs (USDA soil taxonomy). For further details of the site see Ong et al. [1999]. On–farm studies were conducted in Kitui District, which is about 100 km east of Machakos, at an elevation of 1200 m, with bimodal rainfall of 650 mm per annum and Rhodic Ferralsol soils.

Plant material

The study of propagation methods used seedling and cutting material that was all of Kitui origin. The provenance root architecture study used seedlings of four provenances: Kitui, Ishiara, Kibwezi and Siakago, which span different agroclimatic zones [Kenya Soil Survey, 1980] in which melia is an important component of agroforestry systems. Kibwezi has the lowest rainfall (600 mm per annum) and highest mean annual temperature (27.5° C) and Ishiara has the highest rainfall (850 mm) and lowest temperature (22.5° C). On-farm studies were also conducted in Kitui.

Cuttings (root and stem) were taken from a single clone of Kitui provenance. Roots of 1 to 2 cm diameter were severed and cuttings of 5 cm length were dipped in a solution of phthalimide fungicide (Captan50, Drexel Chemical Co., Memphis, Tennessee), containing 0.24% of the active ingredient. Cuttings were then treated with hormone rooting powder (Seradix 3, Murphy Chemicals (EA) Ltd, Nairobi, Kenya) containing 0.8 % indolyl butyric acid. Stem cuttings, (also about 5 cm long) were prepared from young shoots of coppiced melia trees and treated with Captan and IBA as above. Non-mist propagators [Leakey et al. 1990] containing moist sterilised coarse sand were used to root the cuttings. Cuttings that rooted successfully in the propagator (usually after 1 to 2 weeks for root cuttings and [erratically] after several weeks for stem cuttings) were transplanted into 3.6 l black polyethylene pots containing forest top soil and gradually weaned to ambient humidity in open propagators over a period of four weeks. They were then grown on in the nursery, under 60% shade for 10 months before transplanting into the field. There was limited success in producing plants from stem cuttings and only five were transplanted into the field.

The testas of seeds were scarified before sowing them into pots containing forest top soil. The resulting seedlings were maintained under shade before planting into the field.

Experimental details

The propagation method study was planted in November 1997. Separate, adjacent plots were set up for each planting material type, containing 25 seedlings, 25 root cuttings and 5 stem cuttings, planted 3 m apart within plots and with 5 m between plots. At the time of planting, root collar diameters (RCD) did not differ significantly between plant types. They averaged 0.4 cm for seedlings and 0.5 cm for plants raised from root and stem cuttings.

Seedlings for the provenance study were transplanted into the field in April 1996, five months after sowing. Four blocks were planted, each containing a single plot of each of the four provenances. Each plot measured 20 x 30 m and trees were planted in a single line at 1 m intervals, along the central short axis of the plot, which allowed crops to be sown on either side of the tree row. A control plot without trees was also set up in each block. All the plots were sown with maize each season.

Both experimental sites were tractor ploughed before the trees were planted, and the provenance experiment was ploughed at the start of each cropping season. Both trials were weeded twice every growing season, by hand-hoe.

Root architecture assessment

Root architecture in both experiments was determined by excavation. For the propagation method study, these measurements were done 16 months after planting out in the field, when RCD's were approximately 7 cm for plants raised from cuttings and 6 cm for seedlings. Eight root systems were excavated for plants raised from seedlings and root cuttings, and four from stem cuttings. Excavations on the provenance study were done when the plants were 3 years-old. Mean provenance RCD for the studied trees ranged from 9.8 to 10.4 cm. One tree per provenance per block was excavated (*i.e*. four trees per provenance, in total), each tree was selected on the basis that its diameter was closest to the plot mean.

Excavations were conducted within a 2 m x 2 m area centred approximately on the middle of the tree stem. Excavation extended to a depth of 0.5 m in the propagation methods experiment and 0.6 m in the provenance experiment. These depths encompassed the trees' shallow roots, and, as most crop roots are also found at depths less than this [Odhiambo et al., 1999; Odhiambo et al., 2001], the excavation covered the zones in which most tree-crop competition is likely to occur. Beginning adjacent to the stem, individual roots and their branches were excavated using small hand tools. All roots thicker than 0.5 cm diameter at their origin were excavated within the limits of the study area or until their diameters decreased to less than 0.3 cm. To prevent movement during excavation and subsequent measurements, the tree stems were supported by tying them to posts that had been hammered deep into the soil.

Around each of these trees, a 2 m x 2 m levelled grid with 1m x 1m squares was constructed from string. Root diameters were recorded at their origins on the root collar and at each occasion where roots branched or changed direction. Three-dimensional rectangular co-ordinates (distance along and depth from the grid) were also recorded at each of these points. From these measurements, lengths of roots and the angles (from the horizontal) at which they descended into the soil were calculated. For presentation, the root systems were reconstructed from the rectangular co-ordinates and root diameters using Rhinoceros NURBS Modelling Software (IDE, Product Design and Development, Seattle, Washington, USA).

The diameters of first order lateral roots and their immediate angles of descent from root collars were used in conjunction with RCD to determine the index of shallow rootedness [van Noordwijk and Purnomosidhi, 1995] –also termed competitivity index (CI) [Ong et al., 1999]. Because related studies (not described here) compared CI of melia with some other multi-stemmed tree species, the CI calculations presented use measurements of RCD, rather then the customary diameter at breast height (DBH).

CI was also determined for six isolated melia trees that were growing in farmers' fields at Kitui. These trees were aged from three to eight years old and ranged in DBH from 12.6 to 34.7 cm.

Crop yield

In order to determine the relationship between root architecture and crop yield, studies focussed on cropped areas close to trees where competition was greatest. In the provenance experiment, maize cobs were harvested in the long rains of 1999, when trees were three years old. Crop yields were significantly reduced close to trees [Mulatya, 2000], and samples were taken at 1 to 3 m from trees. Cobs were oven dried at 75°C and grains were separated from the cobs before weighing.

Maize yields around the isolated trees in farmers' fields were assessed non-destructively in linear transects that began at the tree stem and extended for up to 21m. Transects was restricted to areas where drainage, soil type and vegetation type appeared uniform. Where possible, data were collected for four transects (N,S,E,W) around each tree but in most cases, fewer transects were measured because of variability in the fields. Yield assessments were made at 2 m intervals along each transect. At each assessment point, cob length and cob diameter of five maize plants that were closest to the assessment position were recorded. Grain dry mass was estimated from the cob volume (assumed to be a cone) using the equation [Mulatya, 2000]

$$\textit{grain dry mass}\ (\mathrm{g}) = 0.39\,\textit{cob volume}\ (\mathrm{cm}^3) - 0.63$$

$$(r^2 = 0.9 \text{ and } p \leq 0.001).$$

Results

Root architecture

First order lateral roots of plants raised from seedlings descended into soils at significantly greater ($p = 0.002$) angles from the horizontal than the roots of plants raised from cuttings, (Table 1, Figure 1). Consequently, plants of seedling origin had significantly ($p = 0.007$) smaller CIs than those from cuttings (Table 1), and held a smaller fraction ($p = 0.026$) of their root system length at shallow depth (Table 1).

There was also a significant positive relationship between the initial angle of descent for first order lateral roots and their overall angle of descent across the whole excavation. The relationship can be described by the following equation:

$$\textit{Overall angle of descent}\ ° = 12.1 + 0.833\ \textit{initial angle of descent}\ °$$

$$(r^2 = 0.51 \text{ and } p = 0.05)$$

Hence roots that initially descend steeply as they develop at the root collar, continue to descend steeply. However, on average, roots of higher branching order that had originated on these first order lateral roots had smaller angles of descent into soils than their parent roots.

There were no significant differences between the mean angles of descent of first order roots of different provenances. However, melia provenances originating in semi-arid conditions had 15 to 22% fewer shallow lateral roots (descending at ≤ 45 ° from the horizontal) than provenances originating in more mesic environments.

CI and crop yields

In the provenance trial, there was a significant negative relationship between mean CI for the trees in each plot and crop yield within 3 m of the rows of trees (Figure 2). Nevertheless r^2 accounted for only 38% of the variation in relative crop yield and thus, other variables are also involved in determining the competitivity of trees. Similarly, for the larger isolated melia trees growing in farmers' fields, the relationship between CI and maize yield within 10 m of the tree trunk, was significant, p = 0.014 (Figure 3).

Discussion and Conclusions

Root architecture of *Melia volkensii* was influenced by the method of propagation, but the root architecture of transplanted seedlings was not influenced by provenance.

Cuttings, irrespective of whether they were derived from stem or root tissues, rooted more shallowly and had greater CIs than transplanted seedlings. This supports previous studies by Riedacker and Belgrand [1983], who found that *Quercus robur* stem cuttings had significantly shallower roots than seedlings. Similarly, Khurana *et al*. [1997] observed that first order roots of stem cuttings of poplar grew horizontally and all vertical roots originated on their plagiotropic lateral roots, rather than from the callus at the base of the cutting. Sasse and Sands [1997] concluded that cuttings of *Eucalyptus globulus* did not produce tap roots and the main structural components of the root systems were derived from adventitious roots. In the present study, not only were cuttings more shallow-rooting, but the orientation of the main axes of lateral roots remained fairly constant along their length, so that they will have an extensive area of influence.

The research station and on-farm observations showed significant negative relationships between CI and crop yield, which suggests that cuttings will be more likely to compete with adjacent crops for below ground resources than seedlings. If the differences between CI's of seedlings and cuttings at 16 months persist, then the regressions between yield and CI for trees aged 3 to 8 years old (Figs. 2 and 3) suggest that the use of cuttings will result in crop yields which are 18 or 54 % of those on plots without trees, (depending on the age and area assessed around the trees). Using seedlings will have less adverse impact on crop yields as yields were 46 and 93% of those on no-tree plots. Consequently, dryland farmers should be encouraged to continue their practice of using seedlings rather than cuttings for restocking their fields. The successful use of CI as a predictor of crop yield in this study contradicts previous findings [Ong et al., 1999] that suggested that it was unreliable when trees were growing together. In the current study, trees were of more similar size and hence problems previously identified may have been avoided.

Evidently, the method of propagation needs to be taken into account in the promotion of this species for dryland farming, and efforts to overcome difficulties in germination continued. Until better seed germination can be achieved, farmers without access to wildlings will continue to use cuttings from which to raise their melia planting stock, which will make their farms less productive. If the use of cuttings is inevitable, root cuttings were a more successful source of planting stock than stem cuttings, but methods of root system management such as root pruning, may need to be adopted to limit competition between trees and crops. Further work is needed to determine if the influence of propagation method on root orientation and CI persist as trees age.

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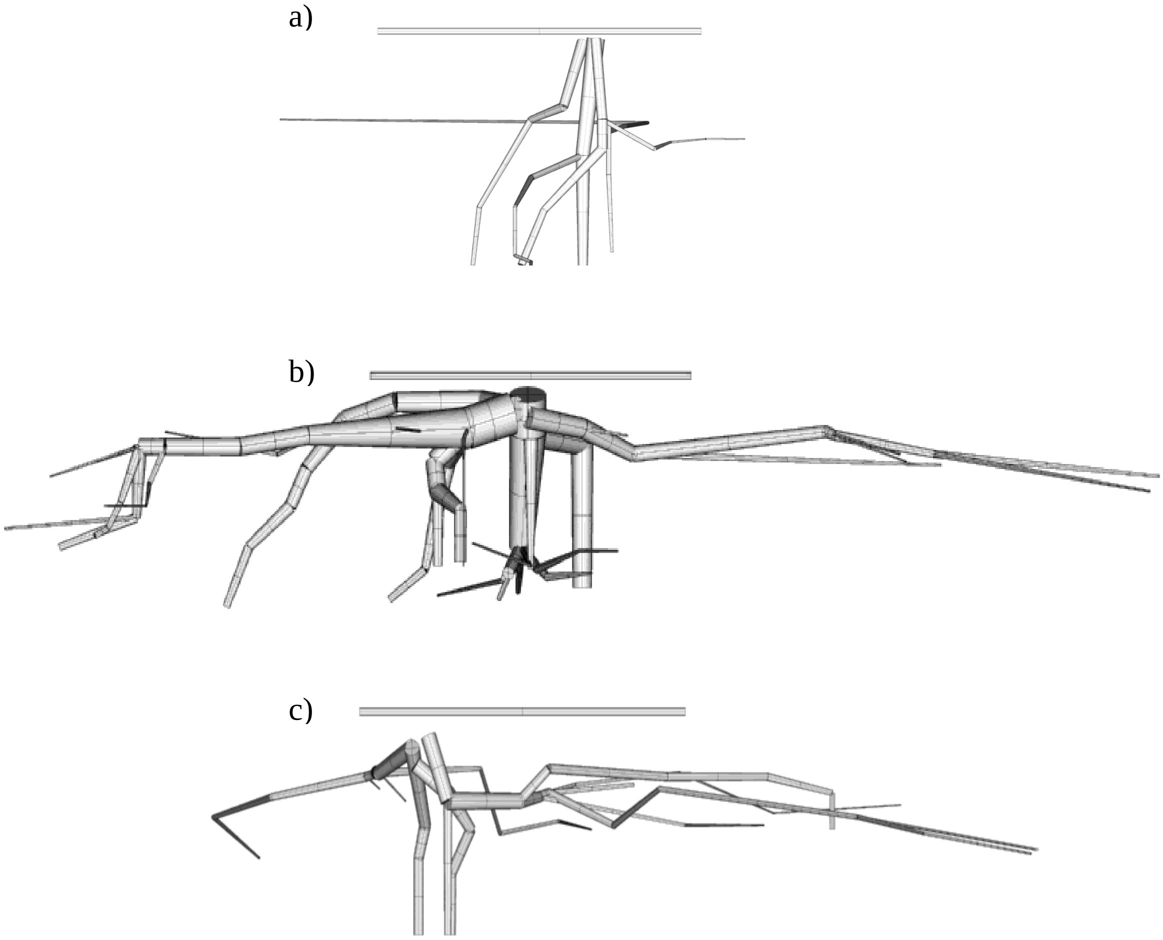
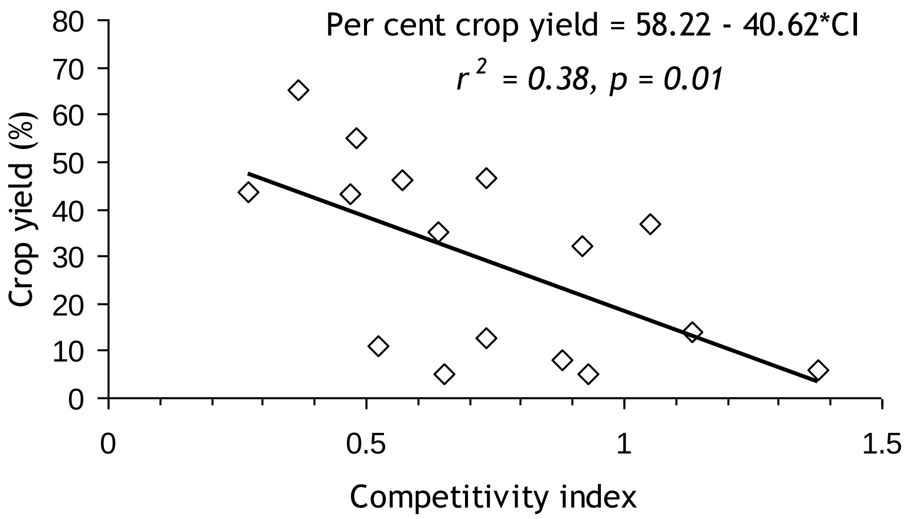
Table 1. Root system variables for *Melia volkensii* plants raised from seedlings, root and stem cuttings growing at Machakos in semi-arid Kenya, Planted April 1996, assessed August 1997.

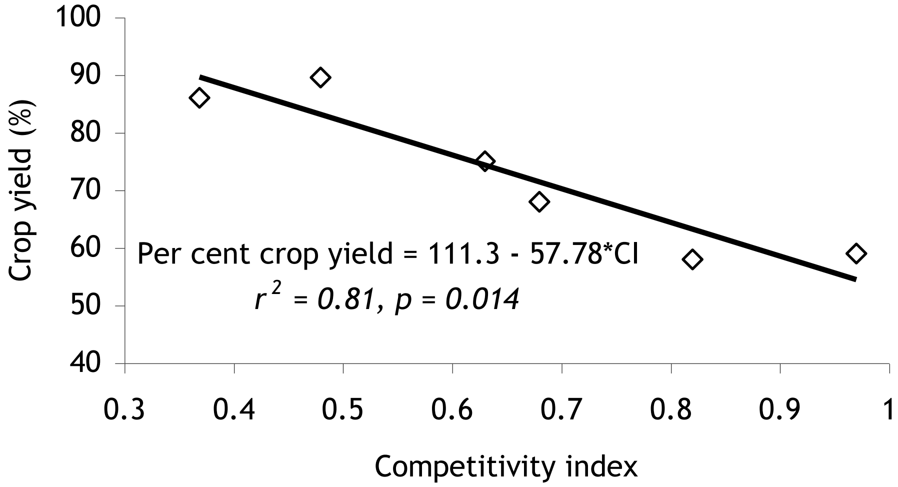
Plant Type	CI	Mean angle of descent (degrees from horizontal) for first order roots	Mean angle of descent from horizontal (degrees) of all root internodes on tree	Fraction of root length existing at soil depths ≤ 40 cm[2]
Seedling	0.31[a1]	54 [a]	33[a]	0.57[a]
Root cutting	1.01[b]	35[b]	24[a]	0.78[b]
Stem cutting	0.99[b]	32[b]	24[a]	0.71[b]
Probability (t-test)	0.007	0.002	0.081	0.026

[1] values in the same column followed by different letters differ significantly from each other at p=0.05.

[2] of roots > 0.3 cm diameter


a)
b)
c)


Per cent crop yield = 58.22 - 40.62*CI
r 2 = 0.38, p = 0.01
Crop yield (%)
0
10
20
30
40
50
60
70
80
0
0.5
1
1.5
Competitivity index


100
90
80
70
60
50
40
Crop yield (%)
Per cent crop yield = 111.3 - 57.78*CI
r² = 0.81, p = 0.014
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Competitivity index

Captions to Figures

Figure 1. Side elevations of typical root architectures of *Melia volkensii* trees raised as a) seedlings, b) stem cuttings and c) root cuttings, 16 months after transplanting them into the field at Machakos, Kenya. In each case, the horizontal bar drawn at ground level is 1 m long. Vertical scale is expanded, excavations were to 50 cm depth.

Figure 2. Relationship between competitivity index and grain yield for maize growing within 3 m of single rows of 4 year-old *Melia volkensii* trees at Machakos in Kenya. Yields are presented as percent of those in control plots lacking trees.

Figure 3. Relationship between competitivity index and maize grain yield within 10 m of isolated *Melia volkensii* trees, aged between 3 and 8 years, growing in farmers' fields at Kitui, Kenya during the long rains in 1999. Yields are presented as percent of those in parts of the field that were not influenced by the presence of trees.