ELSEVIER

Field Crops Research 78 (2002) 185–195

Field Crops Research

www.elsevier.com/locate/fcr

Yield of plantain grown under different tree densities and 'slash and mulch' versus 'slash and burn' management in an agrisilvicultural system in southern Cameroon

L. Norgrove[a,*], S. Hauser[b]

[a]Division of Life Sciences, King's College London, Campden Hill Road, London W8 7AH, UK
[b]International Institute of Tropical Agriculture, Humid Forest Ecoregional Centre, Mbalmayo, Cameroon

Received 1 March 2001; received in revised form 5 July 2002; accepted 11 July 2002

Abstract

Deforestation in the humid tropics poses an increasing threat to natural forests and future timber supplies. Smallholder slash and burn farming and timber extraction are the major causes of deforestation in the Congo basin. Therefore, the feasibility of an alternative to slash and burn, the combination of timber tree production (silviculture) with that of shade-tolerant plantains was tested. French plantain cv. 'Essong' (*Musa* sp. AAB) was grown as an understorey crop, with various crop management treatments: burning; mulching; and intercropping with tannia (*Xanthosoma sagittifolium* (L.) Schott) under two imposed timber stand densities (TSDs), replicated in four blocks, in a 6-year-old *Terminalia ivorensis* (A) Chev. timber plantation in southern Cameroon. No fertiliser, dressing, pesticide or herbicide was applied. Cumulative plant-crop (PC) yields at 1000 days after planting were higher in the low TSD than in the high TSD. The best treatment, low TSD, intercropped and mulched, produced 11.7 Mg ha^{-1} in the plant-crop. Losses were predominantly uprooting of plants.

Keywords: Agroforestry; Burning; Humid tropics; Leaf production rate; Mulching; Tree density

1. Introduction

An alternative for slash and burn farmers in the humid tropics may be to combine timber tree production (silviculture) with that of shade-tolerant crops. Silviculture includes routine slashing of the understorey and reduction of the timber stand density (TSD) by selective felling. The post-thinning phases have reduced competition and greater light availability to the understorey and thus may provide suitable conditions for shade-tolerant crops. Such systems might require a method of managing biomass, other than burning, as this risks scorching the remaining timber trees.

Musa species, which include sweet bananas, plantains and cooking bananas, are referred to by groups which indicate their ploidy and genomic composition with respect to the parent species (A, *Musa acuminata*; B, *M. balbisiana*). Latin names are disregarded. In many parts of the humid tropics, *Musa* spp. have been grown traditionally under trees. For example, under *Casuarina* sp. timber trees in Kompiai gardens in the

* Corresponding author. Present address: IITA Cameroon, c/o Lambourn, 26 Dingwall Road, Croydon CR9 3EE, UK.
Tel.: +237-2209309; fax: +237-2237437.
E-mail address: norgrove@usitmail.com (L. Norgrove).

0378-4290/02/$ – see front matter
PII: S0378-4290(02)00134-X

Papuan New Guinean highlands (Manner, 1981), and under bark cloth trees (*Ficus natalensis* Hochst.) in southwest Uganda (Oduol and Aluma, 1990). However, few studies have investigated the effect of tree or palm density, upon growth and yield of *Musa* spp. and refer only to bananas (reviewed in Norgrove, 1998). Plantain (*Musa* spp. AAB) yield has generally been increased by the use of imported mulch relative to an unmulched control (Wilson et al., 1985; Obiefuna, 1991; Salau et al., 1992), however, no papers have been found comparing 'slash and mulch' with 'slash and burn'. Indeed, there are few references comparing the performance of 'slash and mulch' with 'slash and burn' for any tropical crop (Thurston, 1997).

Musa spp. require a large interrow and interplant space relative to their rooting volume given that leaf length can exceed 4 m and, in plantain, some secondary roots do not produce tertiary roots (Swennen et al., 1986). As it may take 6 months or more before this interrow space is shaded, other crops may be grown successfully in between. Traditionally, *Musa* spp. have been intercropped with yams (*Dioscorea* spp.), aroids (*Alocasia* spp.) and *Piper methysticum* G. Forst in Micronesia (Raynor and Fownes, 1991), and with taro (*Colocasia esculenta* (L.)) in Papua New Guinea (Manner, 1981). However, in south Nigeria, Akinyemi and Tijani-Eniola (2000) demonstrated that intercropping with cassava (*Manihot esculenta* Crantz) reduced plantain yield relative to a sole crop, although Emebiri and Obiefuna (1992) reported that intercropping with cassava reduced the incidence of black sigatoka (*Mycosphaerella fijiensis* Morelet). Also, from Nigeria, Devos and Wilson (1979) reported from a fertilised experiment that intercropping plantain with taro had no significant effect on plantain yield or mean bunch mass.

In southern Cameroon, plantain is the most important food cash crop and is a favoured staple, with an income demand elasticity near one (Temple et al., 1996). Plantain fields are usually prepared by manually clearing the understorey of secondary forest by slash and burn techniques and cutting larger trees with a chainsaw. Few trees are retained. Plantain is commonly planted in an intercrop with cassava, 'egusi' melon (*Cucumeropsis mannii* Naud), and tannia (*Xanthosoma sagittifolium* (L.) Schott), or is planted as a monocrop. Fields are usually abandoned after the harvest of the plant-crop.

Pesticides are rarely used, however, losses, particularly through uprooting of the plant, are high. While banana weevil (*Cosmopolites sordidus* Germar) is recognised by farmers in southern Cameroon, few are aware of root nematodes and thus no measures are taken against them (S. Hauser et al., unpublished). *Radopholus similis* (Cobb) Thorne, which formed 99.6% of the nematode population, by number of individuals, in root samples taken from this experiment (R. Fougain, unpublished), is a migratory endoparasitic nematode causing the destruction of primary roots. *Hoplolaimus pararobustus* Schuurmans, Stekhoven and Teunissen, the only other species found in this experiment (R. Fougain, unpublished) is commonly found in roots but does little damage (Bridge et al., 1995). Root necrosis caused by *R. similis* is characterised by purple to deep purple discoloration yet the stele normally remains white when roots are infested by nematodes alone (Bridge and Gowen, 1993). This often leads to uprooting in wind or heavy rain, particularly when the plant is bearing fruit and thus is already relatively unstable.

An experiment was designed to assess the feasibility of growing plantain (*Musa* spp. AAB 'French' cv. 'Essong') in an agrisilvicultural system with 6-year-old *Terminalia ivorensis* (A) Chev. timber trees as the upperstorey component. The cultivar 'Essong' has been described by Tezenas du Montcel (1979). *T. ivorensis* is commonly known as framiré in francophone Africa and black afara or idigbo in Nigeria (Farmer, 1972); framiré will be used in the following text. As plantains can be perennial, the yield from the planted sucker is the 'plant-crop' (PC) and the yield from the follower sucker sprouting from the same mat 'first ratoon' (R1).

The effects were compared of (1) 'high' versus 'low' TSD and (2) retention of slashed vegetation versus burning and intercropping with tannia on plantain growth, yield and losses up to 1000 days after planting (DAP). The following hypotheses were tested:

- Leaf production rates (LPRs) are reduced under high TSD, thus the growth cycle of the PC is lengthened.
- A longer growth cycle is not associated with any decline in PC bunch mass.

- Burning the slash leads to a reduction in plantain yield.
- Plantain yields are unaffected by intercropping.
- Yields per hectare of the PC and the R1 are greater under low TSD.

Early LPR is usually positively correlated with final bunch mass (Swennen and De Langhe, 1985) thus the relationships between early LPRs, growth cycle length and bunch mass were investigated. Nematode root damage was also assessed.

2. Materials and methods

2.1. Site

The experiment was established in a 6-year-old framiré timber plantation in the Mbalmayo Forest Reserve in southern Cameroon (3°51′N and 11°27′E) in April 1995. The land is covered with semi-deciduous adult and young secondary forest. Altitude is 540 m above sea level. Thirty-year average annual rainfall is 1513 mm in a bimodal distribution. Rains usually start in March and end in early July, followed by a short dry season of 6–8 weeks, then recommence in September and stop at the end of November. The soil is classified as an isohyperthermic, Typic Kandiudult (Hulugalle and Ndi, 1993) and is acid in the subsoil. Initial land clearance in 1989 was manual (Lawson, 1995), however, a few valuable upper-canopy trees were retained.

2.2. Design

The experiment had a factorial split-plot design with 'low' and 'high' TSD treatments as main-plots. There were some trees other than framiré that we were not permitted to fell. These were predominantly *Lophira alata* Banks ex Gaertn. The density imposed for the low TSD treatment was approximately 40 stems ha^{-1} (32 framiré plus 8 other trees). In the high TSD treatments, the stand was thinned to 192 stems ha^{-1}. The experiment was replicated in four blocks, according to position on a gentle slope. Main-plots were 50 m × 50 m.

Different crop managements were sub-plots of which three are described in this paper: sole plantain mulched with the slashed material; intercrop of plantain-tannia mulched with the slashed material; and sole plantain, where the slashed material was burned before planting. Sub-plots were 25 m × 25 m.

Manual slashing of the understorey was started on 17 April 1995 and the tree stand was mapped. TSDs were imposed on 16 May 1995 by felling the shorter or crippled trees first, leaving the marketable timber trees. In the plots to be burned, slash was removed from the zones within 50 cm of standing tree trunks to prevent scorching. Plots were burned on 22 May 1995. Plantain suckers were pared before planting. Plantain density was 1600 plants ha^{-1} on a 2.5 m × 2.5 m square configuration thus 100 plants per sub-plot in all treatments. Tannia planting density was 20 408 plants ha^{-1} on a 0.7 m × 0.7 m square configuration. Planting was from 18 to 24 May 1995 for plantain and from 22 to 24 May 1995 for tannia. No leaves were removed from plantain plants during their growth. No mineral fertiliser, pesticides or herbicides were used. Plots were weeded by manual slashing at 3, 7, 12, 17, 20, 25 and 31 months after planting. Upon flowering, the pseudostem was supported with a prop. At harvest, the largest sucker was selected as the follower ratoon (R1) and any remaining suckers were cut at ground level. The pseudostem of the PC was cut into 30 cm long segments and placed around the R1. The leaves were distributed on the ground around the R1.

2.3. Mapping, tree density parameters, canopy cover, and leaf area index of framiré

The positions of all trees around and within the experiment were measured using an angle prism and a 100 m tape measure. Cartesian coordinates relative to one corner of the experiment were thus calculated. As plantains had been planted at regular distances, their coordinates were calculated mathematically. The minimum horizontal distance in meters from each plantain to the nearest tree was thus calculated using vector analysis. The plot mean of these distances, 'NEAR', was derived. Additionally, the number of trees within a 30 m radius of each plant, converted to a density, such that

$$\mathrm{DEN30(plant)} = \frac{\text{number of trees within 30 m radius}}{30^2\pi} \times 10\,000$$

where DEN30 was the mean of all DEN30(plant) in the plot. To calculate NEAR and DEN30, all trees, whether inside or outside the plots, were considered.

In July 1995, during maximal canopy coverage in each sub-plot, four vertical photographs were taken and the mean canopy cover was visually estimated. Resultant mean canopy covers were 12.4% (low) and 60.9% (high). Maximal leaf area index (LAI_{max}) was calculated from litterfall data using a method adapted from Maass et al. (1995), verified by Eschenbach and Kappen (1996). Full details are given in Norgrove and Hauser (2000).

2.4. Plantain LPRs

Observations were made on 20 plants per sub-plot. Border plants were not used. Plants were selected to represent approximately the range of distances from the nearest framiré in the plot such that the mean 'NEAR' for the 20 plants approximately equalled the plot mean 'NEAR'.

Plants were monitored at 167 DAP and every 4 (rainy season) to 8 (dry season) weeks thereafter. Leaf production was monitored by labelling leaves thus LPRs between samplings could be recorded.

2.5. Harvest and yield parameters

Observations were made on all plants producing an edible bunch, except border plants (64 plants per sub-plot). Plantain bunches were harvested when the fruits on the second fruit hand were convex and filled. The date of harvest, fresh mass of whole bunch including peduncle, number of fruit hands, number of fingers on each hand, mass of each hand, outside length, maximum circumference and mass of the middle finger on each hand were recorded.

Where the plants fell post-flowering, the type of damage causing falling was classified as either uprooting or stem-break (including corm break). Where the bunch was deemed edible by local farmers, it was harvested, bunch characteristics were recorded as above and it was included in the total yield assessment. Where the bunch was deemed inedible, it was cut up, left in the field and not included in the yield analysis. Edible bunches were thus classified into two qualities (Q): Q2, where the bunch was harvested from a standing plant; Q1, where the plant fell before harvest but the bunch was still deemed edible. Yields are presented to 1000 DAP for the PC and to 1300 DAP for the R1.

2.6. Assessment of nematode damage

Plants were assessed for nematode damage at harvest, or upon falling, whether falling was before or after flowering. The method used was adapted from Broadley (1979). A soil monolith, 200 mm × 200 mm × 200 mm was excavated, with one corner adjacent to the corm of the PC stem. All roots were counted and divided into those dead and those alive and numbers were recorded. Five living roots were randomly selected and cut to 10 cm length. The roots were cut longitudinally so that the cortical tissue and stele were visible. Presence or absence of any root knot, indicative of *Meloidogyne* spp., was noted.

A nematode root index on living roots for each plant was then derived by the following equation:

$$\text{nematode root index} = \frac{\text{amount of necrotic cortical tissue}}{\text{total cortical tissue exposed}} \times 100\%$$

where plants fell by uprooting, it was often not possible to excavate a soil monolith as the falling of the plant caused the soil around the base to be dislodged with it, leaving a hole. In this case, root counts were not done and five roots were randomly selected from the side of the exposed corm, then the root index was calculated as above.

The sucker with the largest corm was selected from the fallen plant, pared and replanted adjacent to the original planting hole. The corm and all other infected material was removed. The pseudostem and leaves of the PC were cut into segments and placed around the planted sucker.

2.7. Soil and slash sampling

Soil was sampled in May 1995, at plantain planting. Soil was sampled at nine sampling point-locations per sub-plot using a regular sampling scheme. At each sampling location, slash samples were taken from a 1.41 m × 1.41 m area. Soil was then sampled at five points, at the corners and centre of the sampling area, and bulked by depth: 0–10, 10–20, 20–30, 30–50, 50–70 and 70–100 cm. Samples at 0–10 and 10–20 cm depth were taken with soil cores of 5 cm diameter; deeper layers were sampled using an auger with an internal diameter of 25 mm. Samples were dried at 65 °C for 4 days and passed through a 2.0 mm sieve. A sub-sample of each was ground to 0.5 mm and analysed for pH, organic C, total nitrogen and exchangeable cations. pH was determined in a water suspension at a 2:5 soil:water ratio. Exchangeable calcium, magnesium and potassium were extracted by the Mehlich-3 procedure (Mehlich, 1984). Exchangeable cations were determined by atomic absorption spectrophotometry. Organic carbon was determined by Heanes' improved chromic acid digestion and spectrophotometric procedure (Heanes, 1984). Total nitrogen was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1972).

2.8. Calculations and statistical analyses

Yields (Mg ha^{-1}) of whole fresh bunches were calculated per plot. The means of other yield and vegetative parameters were calculated per plot and means were calculated for Q2 and Q1 groups per plot. Losses were calculated as a percentage of total initial plants. Post-flowering losses were calculated as a percentage of harvested plants.

Data were analysed in SAS v 6.12 using the MIXED procedure with the random statement appropriate for split-plot designs in a two-way ANOVA (SAS, 1989). Data expressed as percentages were transformed such that $Y = \text{arcsine}(\sqrt{y})$, where $0 \leq y \leq 1$ as is appropriate for proportions (Sokal and Rohlf, 1995). All other data analyses were performed on untransformed data. Differences with probabilities of $P < 0.05$ are mentioned with the probability class $P < 0.05$, $P < 0.01$ and $P < 0.001$. For analyses of growth parameters on a subset of 20 plants, distance to the nearest tree (m), NEAR, was used as a covariate and data were analysed using a MIXED model as above.

The sub-plot means ($n = 24$) of shade parameters (canopy cover, the parameters NEAR and DEN30, and LAI), weed biomass at 2 and 7 months after planting (see Norgrove et al., 2000), top soil (0–10 cm) chemical parameters, nematode root index, dead and live root counts were regressed against plant losses in stepwise regressions in PROC REG of SAS with an entry and exit significance of $P < 0.05$.

3. Results

3.1. Leaf production rates

LPRs were initially 0.114 leaves per week higher in low TSD treatments than in high TSD treatments ($P < 0.05$) (Table 1). LPRs were lower in burned than

Table 1
Summary of plot means (20 plants per plot) by treatment of mean LPRs of plantain from 1 to 167 DAP, 168–209 DAP, 210–251 DAP and total number of leaves produced up to flowering[a]

Treatment	LPR days 1–167 (leaves per week)	LPR days 168–209 (leaves per week)	LPR days 210–251 (leaves per week)	Total leaf production[b] (no. of leaves)
High TSD	0.523	0.450	0.309	40.2
Low TSD	0.637	0.559	0.241	41.6
P(TSD)	0.014*	0.13ns[c]	0.24ns	0.14ns
Intercrop, mulched	0.603a	0.550	0.250	40.6
Sole plantain, mulched	0.612a	0.525	0.250	40.3
Sole plantain, burned	0.525b	0.437	0.335	41.8
P(crop management)	0.045*	0.23ns	0.29ns	0.46ns
P(interaction)[d]	0.25ns	0.64ns	0.86ns	0.96ns
P(covariate)	0.26ns	0.99	0.98ns	0.36ns

[a] Mean distance of monitored plants to the nearest tree, NEAR, was used as a covariate ($n = 24$). Where the cropping factor is significant, treatments suffixed by different letters are significantly different from each other at $P_{diff} < 0.05$.
[b] Flowered plants only.
[c] ns: $P > 0.05$.
[d] Interaction refers to TSD × crop management.
* $P < 0.05$.

Table 2
Plantains (PC) that had flowered before and after 1000 DAP and pre-flowering losses, expressed as a percentage of the initial plantain population[a]

Treatment	Total pre-flower losses by 1000 DAP (% of total plants)	Plants flowered by 1000 DAP (% of total plants)	In flower at 1000 DAP (% of total plants)	Flowered after 1000 DAP (% of total plants)
High TSD	59.2	36.3	1.3	3.2
Low TSD	40.2	56.7	1.3	1.8
P(TSD) (S.E.D.)	0.0022** (5.7)	0.0021** (5.6)	0.99ns (0.7)	0.21ns (0.7)
Intercrop, mulched	45.5	50.8	1.2	2.5
Sole plantain, mulched	48.9	48.1	0.8	2.2
Sole plantain, burned	54.8	40.6	1.9	2.7
P(crop management) (S.E.D.)	0.36ns (7.1)	0.32ns (6.7)	0.50ns (0.7)	0.76ns (0.9)
P(interaction)	0.31ns	0.37ns	0.99ns	0.56ns

[a] S.E.D. is standard error of difference between treatments. Where the cropping factor is significant, treatments suffixed by different letters are significantly different from each other at $P_{diff} < 0.05$.
** $P < 0.01$.

in non-burned treatments ($P_{diff} < 0.05$). At later assessments, there were no significant differences between treatments, and rates were reduced during the dry season (210–251 DAP). The number of leaves produced before flowering was not significantly different between TSD or crop management treatments, averaging 40.9 leaves, across treatments.

3.2. Plantain PC losses by 1000 DAP

Total pre-flowering losses of the PC were greater ($P < 0.01$) in the high TSD (Table 2). There was no significant difference between crop management treatments. On average, across treatments, 9% of plants failed to establish (Fig. 1), 39.3% of plants uprooted and 1.4% suffered stem break prior to flowering (data not shown). By 1000 DAP, more ($P < 0.01$) plants had flowered in the low (56.7%) than in the high (36.3%) TSD. Across treatments, 1.3% of plants were still in flower and awaiting harvest at 1000 DAP, with a further 2.5% which flowered after 1000 DAP. There were no significant treatment effects.

Post-flowering losses were predominantly due to uprooting usually resulting in inedible bunches. In the high TSD, 35.7% of flowered plants uprooted and failed to produce an edible bunch, significantly more ($P < 0.001$) than the 16.0% in the low TSD (data not shown). Crop management treatment had no

Table 3
Mean live root index of all PC flowered plants and total root, live root counts and live root index in plants producing a bunch without falling (Q2), $n = 24$[a]

Treatment	Nematode root index, % (mean of all flowered plants)	Total root count no. (mean of Q2 plants)	Live root count no. (mean of Q2 plants)	Nematode root index % (mean of Q2 plants)
High TSD	67.5	13.7	9.9	56.6
Low TSD	69.0	17.2	11.6	66.5
P(TSD) (S.E.D.)	0.75ns (4.6)	0.05* (1.6)	0.35ns (1.74)	0.028* (4.1)
Intercrop, mulched	68.9ab	15.1	10.6	61.3
Sole plantain, mulched	75.8a	14.6	9.6	64.6
Sole plantain, burned	60.1b	16.6	12.0	58.8
P(crop management) (S.E.D.)	0.040* (5.6)	0.62ns (2.1)	0.56ns (2.13)	0.53ns (5.0)
P(interaction)	0.46ns	0.40ns	0.57ns	0.18ns

[a] S.E.D. is standard error of differences between means. Where the cropping factor is significant, treatments suffixed by different letters are significantly different from each other at $P_{diff} < 0.05$. Root counts refer to roots per monolith (8000 cm^3).
* $P < 0.05$.

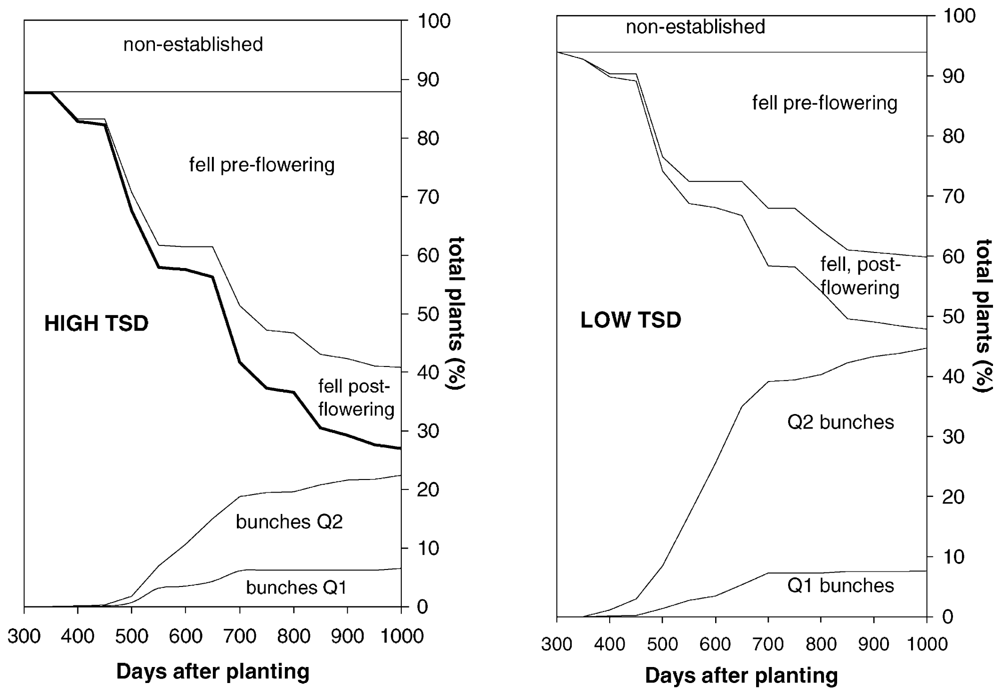

Fig. 1. Pattern of PC plant losses (upper) and plants harvested (lower) of the PC in high and low TSD treatments according to date of falling or date of harvest. The population is separated into plants that did not establish, fell pre-flowering, and fell post-flowering where the bunch was inedible. Plants that produced an edible bunch are divided into Q1, where the plant fell, however, the bunch was edible and Q2, where the bunch was harvested from a standing plant.

significant effect. Plant losses over time are illustrated for high and low TSD treatments (Fig. 1). It is assumed that a fallen plant does not later produce a bunch.

3.3. Root numbers and nematode damage

No plant had root knots therefore *Meloidogyne* spp. were not detected in this experiment. Plants that fell before flowering had on an average 82% nematode root index with no significant difference between TSD ($P = 0.87$) or crop management ($P = 0.70$) treatments (Table 3). It was not possible to test for differences in nematode root index between uprooted and stem break plants because stem break frequency in many plots was zero. There was no significant difference in mean nematode root index for all flowered plants between TSD treatments ($P = 0.75$), however, sole burned treatments had lower ($P < 0.05$) root indices than sole, mulched treatments. For Q2 plants, nematode root index was higher in low TSD treatments ($P < 0.05$). On average, plants from low TSD treatments that produced a bunch without falling (Q2) had more roots at harvest ($P < 0.05$) than those from high TSD treatments. There were no significant differences in live root numbers.

3.4. Plantain PC yield

Fewer ($P < 0.001$) plants produced edible bunches in the high TSD (22.4%) than in the low TSD (44.7%) (Table 4). For bunches harvested from standing plants (Q2), there were no significant differences in bunch mass and characteristics between TSD treatments. However, mean bunch mass was greater ($P < 0.01$) in intercrop than in either sole plantain mulched or sole plantain burned plots as average number of hands and fingers per bunch was higher ($P < 0.05$, $P < 0.01$, respectively). Fresh whole bunch mass yield (Mg ha^{-1}) was reduced ($P < 0.01$) in the high TSD to less than half that in the low TSD (Table 4). The best treatment, low TSD, intercropped and mulched, produced 11.7 Mg ha^{-1}.

Table 4
PC yield of fresh whole bunches, percentage of total plants contributing to yield and bunch characteristics for those harvested from standing plants producing an edible bunch[a]

Treatment	Plants producing edible bunches (% of total plants)	Fresh whole bunch mass (Mg ha^{-1})	Mean fresh whole bunch mass (Q2) (kg)	Hands per bunch (Q2) (No.)	Fingers per bunch (Q2) (No.)
High TSD	22.4	4.43	12.9	6.52	75.6
Low TSD	44.7	9.94	14.7	6.68	79.3
P(TSD) (S.E.D.)	0.0004*** (4.9)	0.0045** (1.65)	0.26ns (1.54)	0.49ns (0.20)	0.46ns (4.6)
Intercrop, mulched	37.0	8.83	16.3a	6.97a	85.3a
Sole plantain, mulched	33.2	7.00	13.4b	6.45b	74.4b
Sole plantain, burned	30.4	5.75	11.7b	6.40b	72.6b
P(crop management) (S.E.D.)	0.56ns (6.0)	0.34ns (2.02)	0.004** (1.10)	0.033* (0.21)	0.024* (4.3)
P(interaction)	0.83ns	0.99ns	0.11ns	0.15ns	0.19ns

[a] Whole bunch mass includes peduncle. Percentage of total plants contributing to yield $= \sum(Q2, Q1)$. Note that bunch characteristics are means for Q2 plants only. S.E.D. is standard error of difference between means.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

3.5. Plantain first ratoon (R1) yield

Ratoon flowering started 734 DAP. Less than 3% of R1s had flowered by 1300 DAP. Two plants in the entire experiment produced edible R1 bunches after the PC had not produced edible bunches. With these exceptions, no R1 bunch was equal or heavier than its PC counterpart. The remaining R1 bunches came from plants which had produced an edible bunch in the PC. Whole, edible bunch mass of producing R1 plants was related to PC bunch size (the two plants where the PC bunch was inedible are excluded):

$$R1 = 0.44 \times PC \quad (r^2 = 0.15, P < 0.05)$$

Forty-two percent of plots produced R1 bunches with a plot maximum of 1.4 Mg ha^{-1} fresh whole bunch mass. This was in the plot which produced the highest PC yield. Treatment means (Mg ha^{-1}) were 0.20 (high TSD), 0.38 (low TSD), 0.47 (intercrop), 0.21 (sole, mulched) and 0.19 (sole, burned) with no significant differences between treatments.

3.6. Topsoil parameters

Topsoil chemical characteristics (mean ± S.E.) across plots ($n = 24$) were pH 5.05 ± 0.08, 1.90 ± 0.11 mg g^{-1} total N, 22.3 ± 0.1 mg g^{-1} organic C, 0.42 ± 0.04 mg g^{-1} exchangeable Ca, 0.10 ± 0.01 mg g^{-1} exchangeable Mg, 0.096 ± 0.012 mg g^{-1} exchangeable K.

3.7. Relationships between losses and tree density and topsoil chemical parameters

DEN30 and soil pH could predict 55% of the between plot variation in total pre-flowering losses using step-wise or forward selection regressions (Table 5). DEN30 was positively correlated with losses, such that losses

Table 5
Relationships between the percentage of pre-flowering PC losses per plot and the mean initial soil nutrient and organic carbon concentration; weed biomass at weedings 2 and 7 MAP; the mean of tree density computed as number of trees within 30 m of any plant, converted to stems ha^{-1} (DEN30); mean distance to the nearest tree (NEAR)[a]

	Variable 1 (direction)	Partial r^2 (*P*)	Variable 2 (direction)	Partial r^2 (*P*)	Model R^2 (*P*)
Plant losses (%)	DEN30 (+ve)	0.45 (0.001)	pH soil (−ve)	0.10 (0.015)	0.55 (0.0003)

[a] Models were obtained by stepwise regressions in PROC REG of SAS with an entry and exit significance of $P < 0.05$. Sub-plot means were used for all variables, thus, $n = 24$.

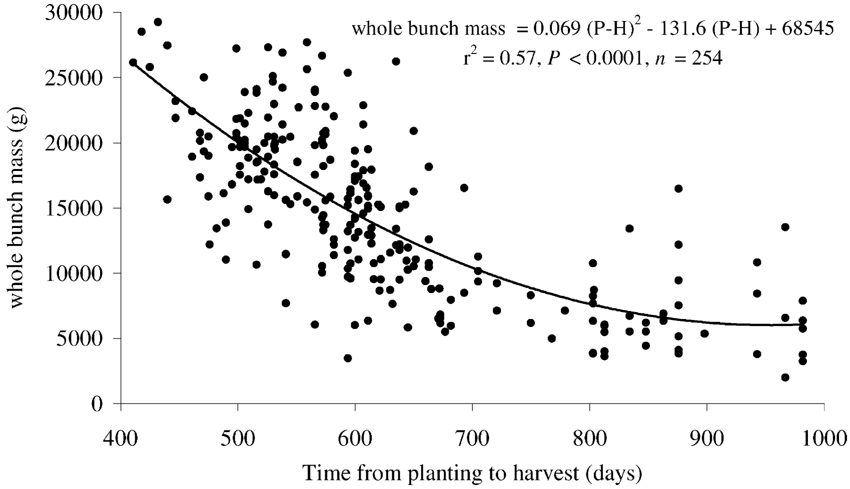

Fig. 2. PC bunch mass decline as a function of time from planting to harvest (P–H) (days). Plants flowering first produced the largest bunches, includes all plants that produced a bunch without falling (Q2), $n = 254$.

were greater at higher DEN30. Soil pH was negatively correlated with losses such that losses were greater at lower pH. However, soil pH and DEN30 were not significantly correlated. The inclusion of these two variables as covariates in the ANOVA analysis greatly reduced the model error, although DEN30 overlapped with the factor tree and thus was insignificant.

3.8. Relationships between time from planting to harvest, LPR and bunch mass

Bunch mass was strongly negatively related to the time from planting to harvest (Fig. 2). Whole bunch mass could also be predicted from the LPR from days 1 to 167 and the relationship was positive, although a lower percentage of variation could be explained:

$$\text{whole bunch mass (g)} = 14\,854 \times \text{LPR} + 2340 \quad (r^2 = 0.14, \underline{P} < 0.0001) \quad n = 154,$$

all monitored plants that produced an edible bunch

The time from planting to harvest (P–H) (days) can be predicted from LPR from days 1 to 167 and the relationship was negative:

$$\text{P–H (days)} = -0.00536 \times \text{LPR} + 1.009 \quad (r^2 = 0.21, \underline{P} < 0.0001) \quad n = 154$$

Relationships with later LPRs were less significant in all cases.

4. Discussion

The low TSD intercropped and mulched treatment produced the highest PC yield (11.7 Mg ha^{-1}) with 50.2% of plants producing edible bunches. At a nearby clear-felled site, in the same years, Hauser (2000) obtained yields of 10.2 Mg ha^{-1} fresh whole bunches of cv. Essong in a treatment with no external inputs, no shade and similar weeding frequencies. This suggests that maintaining a low tree density in fields causes no decline in yields compared to a clear-felled field. No other reference has been found on plantain production without using any external input. In two papers, reporting experiments in which nematicide was used, combined PC and R1 yields of AAB type false horn cv. Agbagba were 13.9 Mg ha^{-1} fresh whole bunches on soil of higher nutrient status but with 300 mm per year less rainfall than Mbalmayo (Obiefuna, 1984) and 16.1 Mg ha^{-1} from low pH but high P soils under high rainfall (Asoegwu and Obiefuna, 1987). In the tropics, under very high input conditions and optimal rainfall, French plantain can produce more than 50 Mg ha^{-1} fresh whole bunches in the PC (Irizarry et al., 1991).

At high TSDs, lower yields per hectare were attained due to greater losses, caused by lower establishment rates, more uprooting pre-flowering and more uprooting post-flowering. Yields were therefore largely determined by number of plants producing rather than bunch mass. The losses were directly related to the tree density. The mechanism by which higher tree densities led to greater losses was not directly investigated in this experiment, however, plants grown in the high TSD had less roots and this may have rendered them more likely to uproot and this may have been exacerbated by the generally high levels of root nematode damage, although root nematode damage was not different between treatments.

The increased bunch mass of plants in intercropped, mulched treatments, relative to those in sole, mulched treatments is difficult to explain, particularly as tannia yields were low and variable, from 4.3 to 364.1 kg ha^{-1} (S. Hauser et al., unpublished). Previous studies from Costa Rica (Rodriguez and Morales, 1988) and Nigeria (Devos and Wilson, 1979) found that intercropping tannia with plantain had no effect upon plantain yield. Weed biomass in intercrop, mulched plots at the weedings in August and December 1995 was on average 78 and 84% of that in sole, mulched plots, yet these differences were not significant (Norgrove, unpublished). The weed community was dominated by *Chromolaena odorata* King & Robinson, an Asteraceae. Initial LPRs of plantain plants were similar between these two treatments. Possibly the tillage-like operation at tannia harvest, in April 1996, improved crop growth through consequent reduced weed competition. Young *C. odorata* has a high concentration of potassium in both stem and leaf material (Norgrove et al., 2000). Plantain leaves, pseudostem and fruits are rich in potassium thus any reduction in weed growth might have a positive impact. Norgrove (1999) estimated that up to 25% of system exchangeable K, where the system comprised all vegetation plus soil to 1 m depth, was taken up by plantains in the low TSD and up to 12% of system exchangeable K was taken up by *C. odorata* weeds in 5-month-old regrowth.

Both higher TSD and burning reduced initial LPRs yet the number of leaves produced before bunch emergence was not different between treatments. Therefore, higher TSD and burning increase planting to harvest time. As planting to harvest time was negatively related to bunch mass, any treatment that increases them is unlikely to increase bunch mass. In Puerto Rico, Goenaga et al. (1993), who compared different levels of irrigation of AAB type false horn cv. Maricongo, showed that agronomic measures that reduced the number of days from planting to flowering resulted in plants with more standing leaves at flowering, more hands, more fingers, heavier fingers and thus heavier bunches.

Few plants had produced a ratoon bunch by 1300 days after establishment and those that did produced bunches less than half the mass of the PC. In Puerto Rico, from a fertigated experiment using AAB type false horn cv. Maricongo, Goenaga et al. (1993) reported a total failure of the ratoon crop with plants lodging approximately 6 months after the harvest of the PC. This was not attributed to nematode or weevil damage, but rather as the indeterminate 'plantain-decline-in-the tropics'-syndrome (Goenaga et al., 1993).

5. Conclusion

Yields obtained were lower and losses from uprooting greater in the high TSD treatments. This was a direct effect of tree density. Thus, the lower tree density is recommended for maximum plantain yield over one cycle.

Acknowledgements

Thanks to F. Gauhl and C. Pasberg-Gauhl for all their support and for training staff in root assessments and to R. Fougain (CARBAP) for supplying data on nematode densities and species. Special thanks to E. Afane Afane IV and P. Mbarga who helped with the measurements. This is IITA manuscript 01/018/JA. L. Norgrove was supported by a King's College London Association scholarship.

References

Akinyemi, S.A.S., Tijani-Eniola, H., 2000. Effects of cassava density on productivity of plantain and cassava intercropping system. Fruits 55, 17–23.

Asoegwu, S.N., Obiefuna, J.C., 1987. Effect of irrigation on late season plantains. Trop. Agric. Trinidad 64, 139–143.

Bremner, J.M., Tabatabai, M.A., 1972. Use of an ammonia electrode for determination of ammonium in Kjeldahl analysis of soils. Commun. Soil Sci. Plant Anal. 3, 71–80.

Bridge, J., Gowen, S.R., 1993. Visual assessment of plant parasitic nematode and weevil damage on bananas and plantain. In: Gold, C.C., Gemmill, B. (Eds.), Biological and integrated control of Highland banana and plantain pests and diseases, Proceedings of the Research Coordination Meeting. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Bridge, J., Price, N.S., Kofi, P., 1995. Plant parasitic nematodes of plantain and other crops in Cameroon, West Africa. Fund. Appl. Nematol. 18, 251–260.

Broadley, R.A., 1979. A simple method for estimating banana root rot. Aust. J. Path. 8, 24–25.

Devos, P., Wilson, G.F., 1979. Intercropping of plantains with food crops: maize, cassava and cocoyams. Fruits 34, 169–174.

Emebiri, L.C., Obiefuna, J.C., 1992. Effects of leaf removal and intercropping on the incidence and severity of black sigatoka disease at the establishment phase of plantains (*Musa* spp. AAB). Agric. Ecosyst. Environ. 39, 213–219.

Eschenbach, C., Kappen, L., 1996. Leaf area index determination in an alder forest: a comparison of three methods. J. Exp. Bot. 47, 1457–1462.

Farmer, R.H., 1972. Handbook of Hardwoods. Her Majesty's Stationary Office, London, UK.

Goenaga, R., Irizarry, H., Gonzalez, E., 1993. Water requirement of plantains (*Musa acuminata* × *Musa balbisiana* AAB) grown under semi-arid conditions. Trop. Agric. Trinidad 70, 3–7.

Hauser, S., 2000. Effects of fertiliser and hot-water treatment upon establishment, survival and yield of plantain (*Musa* spp., AAB, French). Field Crops Res. 66, 213–223.

Heanes, D.L., 1984. Determination of organic C in soils by an improved chromic acid digestion and spectro-photometric procedure. Commun. Soil Sci. Plant Anal. 15, 1191–1213.

Hulugalle, N.R., Ndi, J.N., 1993. Effects of no-tillage and alley cropping on soil properties and crop yields in a Typic Kandiudult of southern Cameroon. Agrofor. Syst. 22, 207–220.

Irizarry, H., Rivera, E., Krikorian, A.D., Rodriguez, J.A., 1991. Proper bunch management of the French-type superplantain (*Musa acuminata* × *M. balbisiana* AAB) in Puerto Rico. J. Agric. Univ. Puerto Rico 75, 163–171.

Lawson, G.J., 1995. Growth of indigenous tree plantations in the Mbalmayo Forest Reserve. Report. Institute of Terrestrial Ecology, Edinburgh.

Maass, J.M., Vose, J.M., Swank, W.T., Martinez Yrizar, A., 1995. Seasonal changes of leaf area index (LAI) in a tropical deciduous forest in west Mexico. For. Ecol. Manage. 74, 171–180.

Manner, H.I., 1981. Ecological succession in new and old swiddens of montane Papua New Guinea. Human Ecol. 9, 359–377.

Mehlich, M., 1984. Mehlich 3 soil test extractant: a modification of the Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15, 1409–1416.

Norgrove, L., 1999. Crop, weed and soil responses to tree density and implications for nutrient cycling in a tropical agrisilvicultural system. Ph.D. Thesis. University of London, UK.

Norgrove, L., 1998. Musa in multistrata systems: focus on shade. Infomusa 7, 17–22.

Norgrove, L., Hauser, S., 2000. Leaf properties, litterfall and nutrient inputs of *Terminalia ivorensis* at different tree stand densities in a tropical timber-food crop multistrata system. Can. J. For. Res. 30, 1400–1409.

Norgrove, L., Hauser, S., Weise, S.F., 2000. Response of *Chromolaena odorata* to timber tree densities in an agrisilvicultural system in Cameroon: aboveground biomass, residue decomposition and nutrient release. Agric. Ecosyst. Environ. 81, 191–207.

Obiefuna, J.C., 1984. Effect of delayed fertiliser application on the growth and yield of plantains in south western Nigeria. Fert. Res. 5, 309–313.

Obiefuna, J.C., 1991. The effect of crop residue mulches on the yield and production pattern of plantain (*Musa* AAB). Biol. Agric. Hort. 8, 71–80.

Oduol, P.A., Aluma, J.R.W., 1990. The banana (*Musa* spp.)—*Coffea robusta*: traditional agroforestry system in Uganda. Agrofor. Syst. 11, 213–226.

Raynor, W.C., Fownes, J.H., 1991. Indigenous agroforestry of Pohnpei. 1. Plant species and cultivars. Agrofor. Syst. 16, 139–157.

Rodriguez, M., Morales, J.L., 1988. Arreglos espaciales en sisternas de platano (*Musa* AAB) y tiquisque blanco (*Xanthosoma sagittifolium* Schott) en La Fortuna de San Carlos, Costa Rica. Agron. Costarric. 12, 219–230.

Salau, O.A., Opara-Nadi, O.A., Swennen, R., 1992. Effects of mulching on soil properties, growth and yield of plantain on a tropical ultisol in southeastern Nigeria. Soil Till. Res. 23, 73–93.

SAS Institute Inc., 1989. SAS/STAT* User's Guide, fourth ed. SAS Institute Inc., Cary, NC.

Sokal, R.R., Rohlf, F.J., 1995. Biometry: The Principles and Practice of Statistics in Biological Sciences, third ed. Freeman, New York.

Swennen, R., De Langhe, E., 1985. Growth parameters of yield of plantain (*Musa* cv. AAB). Ann. Bot. 56, 197–204.

Swennen, R., De Langhe, E., Janssen, J., Decoene, D., 1986. Study of the root development of some *Musa* cultivars om hydroponics. Fruits 41, 515–524.

Tezena du Montcel, H., 1979. Les plantains du Cameroun. Propositions pour leur classification et denominations vernaculaires. Fruits 34, 83–97.

Temple, L., Chataigner, J., Kamajou, F., 1996. Le marché du plantain au Cameroun, des dynamiques de l'offre au fonctionnement du système de commercialisation. Fruits 51, 83–98.

Thurston, H.D., 1997. Slash/mulch systems. Sustainable Methods for Tropical Agriculture. Westview Press, Boulder, CO.

Wilson, G.F., Swennen, R., De Langhe, E., 1985. Effects of mulch and fertiliser on yield and longevity of a medium and giant plantain and a banana cultivar. In: Proceedings of the Third Meeting, IARPB, Abidjan, May 27–31, 1985, pp. 109–111.