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Bunch yield response of two cultivars of plantain (*Musa* spp., AAB, Subgroups French and False horn) to hot-water treatment and fertilizer application planted after forest and bush/grass fallow

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Effects of fallow type, sucker sanitation (hot-water treatment, HWT) and fertilizer application on yield, root and corm health of two plantain cultivars were investigated. Most yield parameters were strongest affected by fallow type with more producing plants, higher bunch mass and yield after forest clearing than in bush/grass fallow. The second most important factor was HWT with more producing plants (52.3%) than in control (35.8%, $p < 0.0001$). Fertilizer application increased the proportion of producing plants by 9%, $p < 0.018$ and yield from 4.08–5.79 Mg ha^{-1}. Combined HWT and fertilizer had strong synergistic effects. Cultivar interacted with fallow and HWT: in bush/grass fallow yield did not differ between cultivars (2.17 Mg ha^{-1}); in forest fallow Essong produced 57% (9.4 Mg ha^{-1}) more than Ebang (6.0 Mg ha^{-1}, $p < 0.001$). Essong yielded 65% more after HWT than Ebang (8.0 versus 4.9 Mg ha^{-1}, $p < 0.001$), yet not when untreated. A limited sink capacity of Ebang is likely to constrain yield increases. HWT improved root and corm health and was better in forest than in bush/grass land. In bush/grass fallow no treatment attained yields as high as in forest even when untreated and not fertilized. Soil chemical properties were not correlated with yield.

Keywords: fallow; fertilizer; forest clearing; plantain; root and corm health; sucker sanitation

Introduction

Plantains (*Musa* spp., AAB) are a major staple food for about 70 million people in West and Central Africa (Ortiz and Vuylsteke 1996; Robinson 1996) and in southern Cameroon it is also the most important commercial food crop. Rapidly developing southern neighbors Gabon and Equatorial Guinea are importing considerable amounts of plantain from Cameroon, to the extent that Cameroonian urban markets register price increases and that the distance to the market has become a major determinant in consumer prices (Ntsama Mbarga 2006). For plantain farmers this development presents a good opportunity to generate cash income. Plantains are usually planted after forest clearing, thus drawing heavily on the natural resource base. Plantains have a high nutrient demand and it was shown that P and K application increased yields even when planted after long forest fallow (Hauser 2000) after which the soil is considered most fertile.

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In addition to apparently insufficient nutrient supply, pest and disease problems are likely to reduce plantain yields. Plantains are highly susceptible to the burrowing nematode *Radopholus similis* Cobb (Thorne) (Price 1994; Fogain 1996; Price and McLaren 1996). Farmers are not aware of the symptoms and consequences of nematode infection and have no means to sanitize planting material. Most plantations are established from suckers cut from existing plantations, bearing a high risk of initial infection. The detrimental effects of *R. similis*, e.g. yield loss and toppling due to root damage are well documented (Davide 1996). A number of control measures are effective against *R. similis*, ranging from nematicide application (Fogain et al. 1996) to sodium hypochloride treatment of suckers (Lordello et al. 1994), treating suckers with biological nematicides (Charles 1995), intercropping with crops antagonistic to nematodes (Charles et al. 1996; Banful et al. 2000), hot-water treatment of suckers (Colbran 1967; Hauser 2000) and replacement of conventional suckers by clean macro-propagated planting materials (Tenkouano et al. 2006). There are no commercial producers of plantain planting material in Cameroon. Thus, an elimination of the nematode by introducing macro-propagated clean planting material is not possible in the short-term. Chemical control has been shown not to be profitable under farmers' conditions (Hauser 2007) while hot-water treatment, although not easily conduced in on-farm situations, has shown a great potential to increase plantain yields (Hauser 2000, 2007). Once the equipment is available the treatment is simple, does not require purchase and handling of toxic substances and can be used for a long time.

Plantain cultivars differ strongly in the average bunch mass produced, whereby even within a cultivar individual bunch masses cover a wide range. Different cultivars have different organoleptic properties and are appreciated accordingly (Ntsama Mbarga 2006). However, no study has been conducted to determine the differences in yield between plantain cultivars which produce large bunches (French types) versus those producing smaller bunches (False horn types) under farmer conditions. Ortiz and Langie (1997) determined bunch masses of different plantain types and showed highly significant differences between False horn and French types, however, on-station, with nematicide and fungicide application and at higher fertilizer rates than used in this trial.

To serve the urban centers without incurring heavy transport costs plantain needs to be produced in urban vicinities where forest has become scarce, while grass and bush fallows are abundant. Farmers do not plant plantain in such fallows because they are deemed unproductive, yet no studies were conducted to establish the differences in plantain yield in forest versus grass/bush fallows.

In urban vicinities farmers have intensified their agricultural operations and fertilizer use is not unusual. However, plantain is not grown frequently there and there are no data on plantain yield response to fertilizer.

To evaluate the importance of the factors pest (nematode) control, cultivar, fallow type and fertilizer use for plantain yield a field trial was conducted in two sites with three farmers in Nkometou, southern Cameroon.

Material and methods

Sites

The experiment was conducted in two sites at Nkometou – Essong Minsang (11°35′ E, 4°05′ N), 30 km north of the capital Yaoundé in southern Cameroon on a Rhodic Kandiudult (Hauser et al. 2005). The area receives between 1200 and 1500 mm of rain annually in a bimodal distribution. Rains start in mid-March and stop at the end of July.

A short dry season follows until the beginning of September. Second season rains stop in mid-November. In each site forest fallow of more than 20 years and grass and bush fallow of approximately 4 years age (mixture of *Chromolaena odorata, Panicum maximum* and *Imperata cylindrica*) were located next to each other. The land was cleared manually, using cutlasses and a chainsaw, in March and April 2000. The slash was retained, not burned.

Design

The design was a split plot, with fallow type being the main plots and the factors cultivar, sucker treatment and fertilizer application randomized within fallow types as a 3 factorial (2 × 2 × 2) design. The main plot, fallow age, had two levels: forest of more than 20 years of age versus grass/bush fallow of 4 years of age. Within these two fallow types the first factor was plantain cultivar at two levels: cultivar Essong (*Musa* spp, AAB, French) and cultivar Ebang (*Musa* spp, AAB, False horn); second factor was fertilizer application at two levels: no fertilizer versus application of NPK at 200-40-200 kg ha^{-1}; third factor was sucker treatment at two levels: traditionally prepared suckers versus hot-water treated suckers. All treatments were replicated four times.

Planting material and planting patterns

Plantain suckers of the local cultivars Essong and Ebang were purchased from farmers. The experiment was planted between 7 and 19 May 2000, by replicate. Suckers were randomly separated into two sets. One set was treated with hot water at 52°C for 20 min (Colbran 1967; Hauser 2000), the other prepared in the traditional way, by crudely removing rotten and strongly discolored tissue. This traditional sucker preparation does not correspond to ‘paring’, where the entire surface of the corm is removed until only white tissue remains. Farmers do not remove all discolored tissue but largely the black and dark brown portions. Plantains were planted on the same day as they were treated. Plots measured 12.5 × 12.5 m, planting holes of 0.2 × 0.2 × 0.2m were dug at 2.5 × 2.5m distance on a square configuration, thus plots had 25 plants at a density of 1600 plants ha^{-1} or 6.25 m^2 plant^{-1}.

Fertilizer application

Plants received 128 g of Triple Super Phosphate equivalent to 25 g plant^{-1} of P or 40 kg ha^{-1} of P, as a single application into the planting hole. A total of 200 kg ha^{-1} of nitrogen and potassium were applied in five dressings of 40 kg ha^{-1} of N and 40 kg ha^{-1} of K, equivalent to 25 g plant^{-1} N or 54 g plant^{-1} of urea and 25 g K plant^{-1} or 50 g plant^{-1} of potassium chloride on 8 August 2000, 23 October 2000, 4 May 2001, 16 October 2001 and on 15 May 2002.

Weeding

Due to the presence of *Imperata cylindrica*, which can severely interfere with plantain corms by penetrating corms with rhizomes, 6 liters ha^{-1} of Round up®, active ingredient 360g l^{-1} glyphosate, were applied during the first week of June 2000, i.e. after planting plantains. The herbicide was applied in all plots with a knapsack sprayer. Plantains were covered with paper bags to avoid damage. Manual weeding was conducted in June (herbicide application survivors), August and September 2000, in April, July and

September 2001, in January, May and August 2002, using cutlasses to slash all aboveground weed biomass.

Observations on the plantain

Plant emergence was evaluated on 17–19 July 2000; two months after planting (MAP) and a second time from 18–22 September 2000 (4 MAP).

At harvest or when found uprooted or with a broken pseudostem, the number of living leaves, the pseudostem height and circumference were recorded. The bunch was cut off between the first and second empty bract and weighed fresh. Bunches of uprooted or broken plants were evaluated for the quality of the fruits. If deemed edible by the farmer, the bunch mass was included in the yield analyses. If a bunch was not deemed edible or a plant did not produce a bunch the value zero was considered in yield determination.

Nematode damage was assessed at harvest or when found uprooted or with broken pseudostem on every plant, using a method adapted from Broadley (1979), reviewed by Bridge and Gowen (1993). A soil monolith of 20 × 20 × 20 cm was excavated, with one corner adjacent to the corm. All roots were sorted into dead and living ones and counted. Five living roots were randomly selected and cut to 10 cm length, then cut longitudinally to expose corticle and steele. If plants were uprooted, excavation and count of roots was not possible. In such cases five roots were randomly selected from the exposed corm. Nematode damaged tissue is dark purple to black as compared to the unaffected white corticle tissue. A 'root necrosis index' (RNI) was derived as:

$$\mathrm{RNI} = (\text{surface of necrotic cortical tissue}/\text{total surface of cortical tissue}) \times 100\%$$

To consider both the number of living roots and the level of nematode damage a 'non-damaged roots index' (NDRI) (Hauser 2000) was calculated as:

$$\mathrm{NDRI} = \text{number of living roots} \times (100 - \mathrm{RNI})$$

After assessment, plants were cut at ground level. The largest sucker was retained to grow the ratoon. All other suckers were cut off. Plants were not de-suckered at any other time than at harvest. Data collection was terminated mid May 2003, about 36 MAP, however, no plants produced an edible bunch in the last four months of the trial.

Soil analysis

Soil was sampled with a 20 mm diameter auger at 0–10, 10–20 and 20–30 cm depth within the first month after planting plantains. Soil was oven dried at 65°C and ground to pass a 2 mm mesh size sieve. Exchangeable K^+ and available P were extracted by the Mehlich-3 procedure (Mehlich 1984). Cations were determined by atomic absorption spectrophotometry and P by the malachite green colorimetric procedure (Motomizu et al. 1983). Organic C was determined by chromic acid digestion and spectrophotometric procedure (Heanes 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai 1972; Bremner and Mulvaney 1982).

Data analysis

Statistical analyses of the yield, bunch mass per producing plant, the NDRI and other directly measured parameters were conducted on untransformed data. Percentages were analyzed after 'arcsine' transformation using the GLM procedure in SAS release 6.12 (SAS 1997). Least square means were calculated and the levels of significance of differences between means (p diff) are given up to a level of $p = 0.05$.

Results

Soil chemical properties

Soil pH, total N, organic C and exchangeable Ca were higher in the forest fallow in the 0–10 cm layer than in the grass/bush fallow (Table 1). At 10–20 cm depth only total N was higher in the forest soil, while at 20–30 cm depth organic C, available P and exchangeable K were higher in the forest soil.

Plant crop emergence, flowering and plant losses

At 4 MAP on average across all treatments 4.9% of the suckers had not emerged. Sucker treatment interacted significantly with cultivar such that in the cultivar Ebang the hot-water treatment (3.25% failure) had no effect (4.5% failure in control, ns) while in cultivar Essong the rate of failure to emerge dropped from 10.5% in control to 1.25% after hot-water treatment ($p < 0.001$) When untreated the cultivar difference was significant ($p < 0.003$), yet not after hot-water treatment.

Pre- and post-flowering plant losses of the plant crop (PC) were caused by uprooting, pseudostem break and the death of plants caused by unspecific corm rots or severe banana weevil attack. Across all treatments 11.7% of plants were lost to either of these causes. The total proportion of plants lost was affected by fallow type, sucker treatment and fertilizer application, yet not by cultivar (Table 2). None of the factors interacted significantly. The individual causes of plant loss were affected in different ways by the treatments: hot-water treatment of suckers reduced, while fertilizer application increased the proportion of uprooted plants. In forest fallow a lower proportion of plants died, yet a higher proportion

Table 1. Soil chemical properties at Nkometou, southern Cameroon, at the beginning of the plantain trial.

Soil depth	Fallow type	Soil pH	Total N ($g\ kg^{-1}$)	Organic C ($g\ kg^{-1}$)	C/N	Available P ($mg\ kg^{-1}$)	Exch Ca cmol $[+]kg^{-1}$	Exch K cmol $[+]kg^{-1}$
0–10 cm	Bush/grass	5.96	2.01	23.5	11.60	12.00	4.83	0.232
	Forest	6.15	2.39	26.6	10.92	14.27	8.31	0.233
	p diff	0.012	<0.001	0.002	0.009	ns	<0.001	ns
10–20 cm	Bush/grass	5.95	1.77	25.6	15.09	9.66	4.12	0.176
	Forest	5.79	1.94	24.8	13.26	9.89	5.05	0.162
	p diff	0.032	0.018	ns	<0.001	ns	ns	ns
20–30 cm	Bush/grass	5.62	1.04	12.4	12.13	3.14	2.00	0.085
	Forest	5.53	1.02	14.9	14.31	3.82	1.76	0.095
	p diff	ns	ns	<0.001	<0.001	0.026	ns	0.039

Table 2. Proportion* of plants lost to uprooting, pseudostem break and death from either unspecific corm rot or banana weevil attack and total losses (%) by fallow type, sucker treatment, fertilizer application and cultivar; Nkometou, southern Cameroon.

Fallow type	Forest	Bush/grass	*p* diff
Uprooted	6.28	6.12	ns
Pseudostem break	7.60	1.12	<0.0001
Died	0.42	1.88	0.006
Total losses	14.30	9.12	<0.0001
Sucker treatment	Hot-water	Control	*p* diff
Uprooted	3.03	9.37	<0.0001
Pseudostem break	4.11	4.63	ns
Died	0.93	1.38	ns
Total losses	8.07	15.38	0.0004
Fertilizer application	Fertilizer	nil	*p* diff
Uprooted	8.40	4.00	0.0021
Pseudostem break	3.61	5.13	ns
Died	1.05	1.25	ns
Total losses	13.06	10.38	0.0157
Cultivar	Essong	Ebang	*p* diff
Uprooted	5.87	6.53	ns
Pseudostem break	3.88	4.85	ns
Died	1.38	1.03	ns
Total losses	11.13	12.41	ns

*Percent data were analyzed as ARCUS SINUS transformed values; here re-transformed data are presented for easier reading.

suffered pseudostem break than in bush/grass fallow (Table 2). Post-flowering losses (premature uprooting, breaking of the pseudostem) ranged from 0–15% with an average of 6.9%, thus contributing about half of the total plant losses. Post-flowering losses were twice as high in the forest fallow (9.5%) than in the bush/grass fallow (4.25%).

At 36 MAP, on average across treatments 44% of the plantains had flowered with a range of 9–78%. All treatments affected the proportion of plants that had reached flowering (Table 3) yet none of the factors interacted significantly. The largest treatment effects were attained by fallow type (forest > bush/grass fallow) and sucker treatment (hot-water treatment > control). Fertilizer application increased the proportion of flowering plants by about 9%. More plants of the cultivar Ebang reached flowering than of cultivar Essong.

On average 47.4% of the plants were still alive yet had not reached flowering at 36 MAP. After forest clearing 29.5% of plants had not flowered versus 65.3% ($p < 0.0001$) in bush/grass fallow. Most plants that had not reached flowering were very small thus had not grown sufficiently to produce a flower.

Bunch production and yield

Across all treatments, about 36% of the plant crop plantains produced an edible bunch. All treatments affected the proportion of producing plants, yet none of the factors interacted significantly. A higher proportion of plants produced edible bunches in forest fallow than in bush/grass fallow (Table 4), and a higher proportion produced after hot-water treatment than in control. Fertilizer application increased the proportion of producing plants and the cultivar Ebang had a higher rate of producing plants than Essong. Most plantain bunches were harvested from standing plants (Table 4). However, a small proportion of plants had reached bunch maturity when they either uprooted or had

Table 3. Proportion* of plants (%) that had flowered by 36 months after planting by fallow type, sucker treatment, fertilizer application and cultivar; Nkometou, southern Cameroon.

Fallow type	Bush/grass	Forest	*p* diff	Difference
	26.1	61.9	<0.0001	35.8
Sucker treatment	Control	Hot-water		
	35.8	52.3	<0.0001	16.5
Fertilizer application	nil	Fertilizer		
	39.4	48.6	0.0179	9.3
Cultivar	Essong	Ebang		
	39.5	48.5	0.021	9.0

*Percent data were analyzed as ARCUS SINUS transformed values; here re-transformed data are presented for easier reading.

Table 4. Proportion* of plants that produced an edible bunch and were at harvest standing, had uprooted or pseudostem break and total proportion of producing plants (%) by fallow type, sucker treatment, fertilizer application and cultivar; Nkometou, southern Cameroon.

Fallow type	Bush/grass	Forest	*p* diff
Produced standing	20.7	45.0	<0.0001
Produced uprooted	0.1	3.2	<0.0001
Produced stem break	0.1	3.0	0.0034
Total	20.9	51.2	<0.0001
Sucker treatment	Control	Hot-water	*p* diff
Produced standing	22.9	42.7	<0.0001
Produced uprooted	2.6	0.8	0.0086
Produced stem break	1.1	2.0	ns
Total	26.6	45.4	<0.0001
Fertilizer application	Nil	Fertilizer	*p* diff
Produced standing	28.6	37.0	0.0189
Produced uprooted	0.9	2.5	0.0211
Produced stem break	1.0	2.1	ns
Total	30.5	41.6	0.004
Cultivar	Essong	Ebang	*p* diff
Produced standing	27.5	38.1	0.004
Produced uprooted	1.9	1.5	ns
Produced stem break	2.4	0.7	ns
Total	31.7	40.3	0.011

*Percent data were analyzed as ARCUS SINUS transformed values; here re-transformed data are presented for easier reading.

a break of the pseudostem. Hot-water treatment reduced the proportion of plants with edible bunches that uprooted. In the bush/grass fallow a lower proportion of plants with edible bunches either uprooted or had broken pseudostems than in the forest fallow.

The mean time required by the plant crop to produce a bunch (time from planting to harvest) was almost five months shorter in the forest fallow (575 days) than in the bush/grass fallow (716 days, $p < 0.0001$) and shorter when fertilizer was applied (621 days) than when no fertilizer was applied (670 days, $p < 0.009$). The cultivar Ebang required less time (616 days) than the cultivar Essong (675 days, $p < 0.002$). Hot-water treatment shortened the time from planting to harvest (630 days) by one month (661 days), yet not significantly ($p = 0.1$).

The fresh bunch yield of the plant crop was affected by each treatment factor and the factor cultivar interacted with sucker treatment and with fallow type. Fertilizer application increased fresh bunch yield from 4.08–5.79 Mg ha^{-1} ($p < 0.005$). In the bush/grass fallow the cultivars did not differ in bunch yield (Table 5), while Essong produced a 57% higher yield than Ebang in the forest fallow. When the suckers were not hot-water treated the cultivars did not differ in bunch yield. After hot-water treatment the cultivar Essong attained a 65% higher yield than Ebang (Table 5).

The fertilizer × sucker treatment interaction failed the 0.05 significance level ($p < 0.065$) but data strongly indicate that in both cultivars fertilizer caused a higher yield increase if suckers had been treated in hot water. In both cultivars and both fallow types fertilizer application alone had a smaller yield increment than hot-water treatment alone (Figure 1).

Relative yield increments were higher in the bush/grass fallow than in forest (Figure 2). In the bush/grass fallow, hot-water treatment caused the largest relative yield increases. In the forest fertilizer application caused virtually no yield increment while hot-water treatment caused 14–46% yield increase. In the forest the largest increments were attained by the synergy of fertilizer and sucker treatment, which were in both cultivars larger than the sum of fertilizer plus hot-water treatment. In the bush/grass fallow the synergistic effect of combined hot-water treatment and fertilizer was relatively small.

The bunch mass of the producing plant crop was higher after hot-water treatment (7.94 kg) than when not treated (6.99 kg; $p = 0.034$). The cultivar Essong produced heavier bunches (9.56 kg) than Ebang (5.37 kg; $p < 0.0001$) whereby cultivar interacted with fallow type, such that in cultivar Essong the bunch mass in forest fallow (12.09 kg) was 72% higher than in bush/grass fallow (7.04 kg, $p < 0.0001$), whereas in cultivar Ebang bunches in the forest were 50% heavier at 6.46 kg vs. 4.29 kg in bush/grass fallow ($p < 0.001$).

Table 5. Plantain fresh bunch yield (Mg ha^{-1}) as affected by cultivar and fallow type and sucker treatment, Nkometou, southern Cameroon.

Cultivar	Forest	Bush/grass	p diff$_{(fallow)}$
Ebang	5.976	2.016	<0.001
Essong	9.406	2.336	<0.001
P$_{(Cultivar)}$	<0.001	ns	$p_{(interaction)} = 0.011$
Sucker treatment	Hot-water	Control	p diff$_{(treatment)}$
Ebang	4.878	3.114	<0.038
Essong	8.028	3.174	<0.001
p diff$_{(Cultivar)}$	<0.001	ns	$p_{(interaction)} = 0.034$

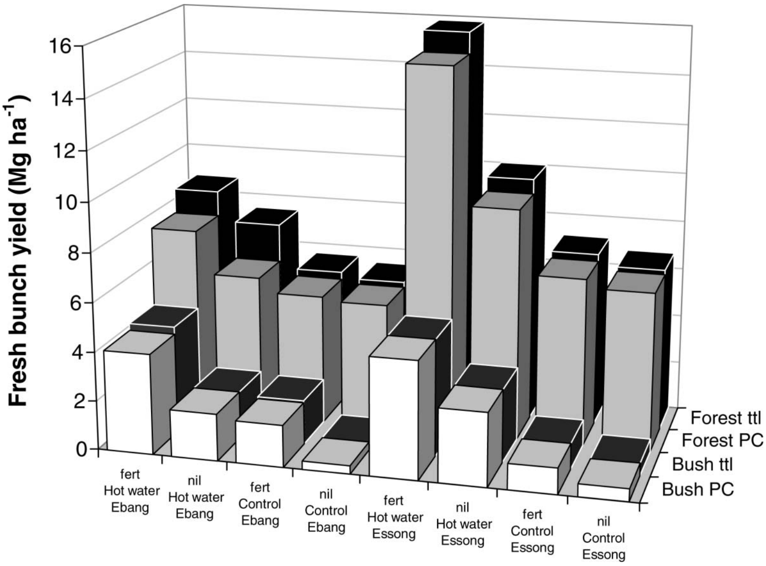

Figure 1. Fresh bunch yield of two plantain cultivars planted in degraded bush/grass and non-degraded forest fallow, with and without fertilizer after hot-water treatment versus no treatment of the suckers; Nkometou, southern Cameroon. fert, fertilizer applied; PC, plant crop; ttl, plant crop plus ratoon yield.

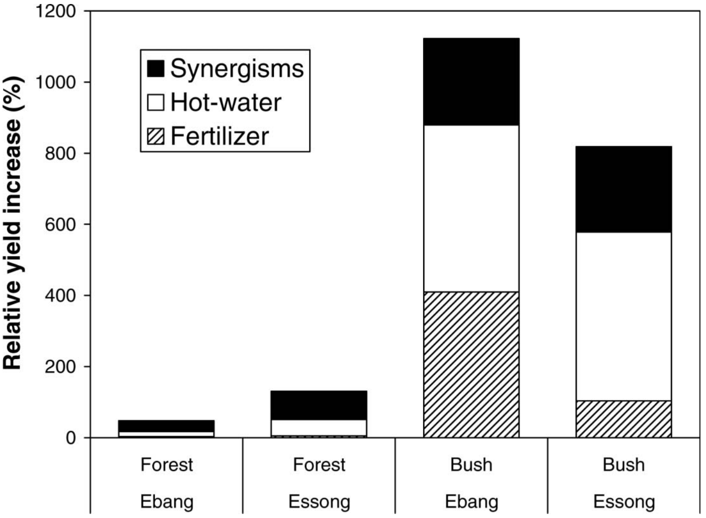

Figure 2. Relative yield increase (%) caused by fertilizer application only, hot-water treatment only and the synergistic effects of the combination of fertilizer application and hot-water treatment; Nkometou, southern Cameroon.

Bunch production by the ratoons was low; between 0 and 13% of the plants produced an edible ratoon bunch. The proportion of ratoon bunch producing plants was affected by cultivar, sucker treatment and fallow type, with cultivar × sucker treatment, cultivar × fallow type and sucker treatment × fallow type interactions (Table 6). The yield of the ratoons and their relative contribution to the total bunch yield was low. The cultivar Ebang had a higher ratoon yield (0.430 Mg ha^{-1}) than Essong (0.239 Mg ha^{-1}, $p = 0.042$) and accordingly in Ebang the ratoons' contribution to the total yield was higher (6.8%) than in Essong (2.0%, $p = 0.0013$). Ratoon yield had a sucker treatment × fallow type interaction such that in the bush/grass fallow yield after sucker treatment (0.072 Mg ha^{-1}) did not differ from the control (0.020 Mg ha^{-1}) yet in the forest hot-water treatment produced significantly more (1.01 Mg ha^{-1}) than control (0.24 Mg ha^{-1}, $p < 0.0001$).The relative contribution to the total yield followed the same pattern ranging from 1–11.5%.

The total fresh bunch yields (plant crop plus ratoons) followed the same pattern as the yields of the plant crop (Figure 1). The cultivar Essong produced no ratoons in the bush/grass fallow, while the cultivar Ebang had small ratoon increments when fertilizer was applied and when suckers had been treated and fertilized. In the forest fallow all treatments produced ratoon bunches.

Root and corm health

Hot-water treatment increased the number of living roots and the NDRI and decreased the number of dead roots and the RNI (Table 7). The RNI was higher in the bush/grass fallow (29.6) than in the forest fallow (19.8; $p = 0.047$) and higher on plants that had received fertilizer (30.9) than on unfertilized plants (18.5; $p = 0.014$). For the number of live and dead roots and the NDRI significant cultivar × fallow type interactions were found (Table 8).

Table 6. Proportion of plants (%) that produced an edible ratoon bunch, Nkometou, southern Cameroon.

	Cultivar			Fallow type		
Sucker treatment	Ebang	Essong	*p* diff	Bush	Forest	*p* diff
Control	1.75	0.75	ns	0.25	2.25	ns
Hot-water	6.35	1.75	0.0002	0.75	7.35	<0.0001
p diff	0.0002	ns		ns	<0.0001	
Fallow type	Ebang	Essong	*p* diff			
Bush	1.00	0.00	ns			
Forest	7.10	2.50	0.0002			
p diff	<0.0001	0.031				

Table 7. Number of live roots, dead roots, the Root Necrosis Index (RNI) and the Non-Damaged Root Index (NDRI) of plant crop plantains at harvest or when found uprooted or with a broken pseudostem; Nkometou, southern Cameroon.

Sucker treatment	live roots	dead roots	RNI	NDRI
Control	8.91	5.34	35.8	739.4
Hot-water	13.89	3.71	13.6	1237.2
p diff	<0.0001	0.0007	<0.0001	<0.0001

Relationships

The fresh bunch yield of both cultivars was significantly correlated with the proportion of plants that had produced an edible bunch, the individual bunch mass and the mean time elapsed between planting and harvest (Table 9). In the cultivar Essong these correlations were closer than in the cultivar Ebang. In the cultivar Ebang the fresh bunch yield was positively correlated with the NDRI. On an individual plot basis none of the soil chemical properties was correlated with fresh bunch yield.

Discussion

An emergence rate of 95.1% (4.9% failure) can be considered high. Conventional suckers usually sustain plant losses in the vicinity of 10%. Obiefuna (1986) reported failure to establish of 3–15%, Hauser (2000) using cultivar Essong, reported 9–15% and Norgrove and Hauser (2002) reported 6–12% of cultivar Essong. In a different trial Mekoa and Hauser (submitted) found 99.3% establishment of the cultivar Ebang at 3 MAP, independent of sucker treatment, which may be an indication of Ebang being less susceptible to constraints at emergence. The significant increase in emergence of Essong

Table 8. Number of live roots and of dead roots and of the Non-Damaged Root Index (NDRI) of plant crop plantains at harvest or when found uprooted or with a broken pseudostem; Nkometou, southern Cameroon.

		Cultivar		
	Fallow type	Ebang	Essong	*p* diff
Live roots	Bush	6.53	10.76	0.0062
	Forest	15.45	12.88	ns
	p diff	<0.0001	ns	
Dead roots	Bush	4.39	4.22	ns
	Forest	3.72	5.77	0.0015
	p diff	ns	0.0157	
NDRI	Bush	545.5	952.6	0.007
	Forest	1373.6	1081.4	0.0364
	p diff	<0.0001	ns	

Table 9. Coefficients of determination (r^2) and p values of correlations between plant crop fresh bunch yield (Mg ha^{-1}) and the percentage of plants that produced a bunch, the mean bunch mass of producing plants, the mean time elapsed between planting and harvest, the Non-Damaged Root Index (NDRI) and the Root Necrosis Index (RNI).

		% plants producing	Bunch mass (kg)	Planting to harvest (days)	NDRI	RNI
Ebang	r^2	0.359	0.659	-0.339	0.189	ns
	p	0.0005	<0.0001	0.0007	0.02	
Essong	r^2	0.555	0.769	-0.584	ns	ns
	p	<0.0001	<0.0001	<0.0001		

after hot-water treatment may indicate that the cultivar suffers pest and disease related plant losses at emergence.

Pre- and post-flowering plant losses in the cultivar Essong were lower in this trial than in another trial where 17% of plants were lost pre- and another 14% post-flowering (Hauser 2007). The loss-reduction of hot-water treatment (Hauser 2000), specifically the reduction in uprooted plants has thus been confirmed on-farm and may be an indicator of the hot-water treatment effectively reducing nematode infestation. This is affirmed by the lower RNI and the higher NDRI and number of living roots (Table 7) when suckers were treated. The higher losses in forest than in bush/grass fallow and when fertilizer was applied versus nil cannot be compared to other data. However, the heavier bunches of both cultivars in forest may have contributed to these losses through increasing the mechanical risk of toppling or breaking. The fallow type × cultivar interaction shows that Ebang had a better root system when grown in forest, while the root system of Essong had little response to fallow type. The higher number of dead roots of cultivar Essong in forest is not a suitable indicator of susceptibility to failing, since, except for mechanical imbalance, it remains unexplained why higher plant losses occurred in the forest despite a better root system on plants grown there.

The proportion of flowered plants in this trial has to be considered low as compared to data on the cultivar Essong, with 1.5–8.9% of plants of the plant crop not having flowered by 42 MAP (Hauser 2000). For the cultivar Ebang, no comparable data could be found. The effects of sucker treatment and fertilizer application found in the present study are different from those reported by Hauser (2000). Here hot-water treatment increased the rate of flowered plants, while Hauser (2000) reported a reduction, albeit a small one. It has to be assumed that the on-farm trial was conducted under less favorable conditions caused by site properties, annual variations and lower levels of maintenance (weeding) than the on-station trial. With almost all plants reaching flowering on-station no or little treatment effects can be shown. Under constrained conditions on-farm the positive effect of sucker sanitation did show an effect. In the present trial and the one reported by Hauser (2000) fertilizer application increased the proportion of flowering plants.

Fallow type had the strongest effect on the proportion of flowered plants. There is no information with which to compare these results.

The proportion of plants that produced an edible bunch, irrespectively of whether the plant was standing, had uprooted or a broken pseudostem at harvest was about 21% in bush/grass fallow and 51% in forest fallow. The data from the bush/grass fallow cannot be compared to other data. However, with 79% of plants failing to produce, the situation in the bush/grass fallow is close to reports from Ghana with failure rates ranging from 53–74% (Mensah-Bonsu et al. 1999) and data from a shaded multi-strata system in Cameroon with 56–78% non-producing plants (Norgrove and Hauser 2002). Achard and Sama Lang (1999) reported 23–90% failure to produce from south-western Cameroon. Thus rates of producing plants in the bush/grass fallow are at the low end of the reported range. The failure rate in the forest, of 49%, is well within proportions reported by Hauser (2007) ranging from 55–32%, and from 29–50% Hauser (2000). The positive effect of hot-water treatment on the rate of producing plants (+18.8%) in the present trial was higher than reported by Hauser (2000) where an insignificant increase of 5% was attained on-station, yet lower than reported by Hauser (2007) of 22.4% for the cultivar Essong on-farm. The positive effect of fertilizer (+11.1% producing plants) was only about half as much as reported by Hauser (2000) where 20.6% more plants produced an edible bunch. Generally sucker treatment and fertilizer had positive effects on the rate of producing plants which, in previous trials, had a stronger impact on the fresh bunch yield than the bunch mass

(Hauser 2000). The higher rate of producing plants of cultivar Ebang may be a genotypic trait.

The average bunch mass of the False horn cultivar Ebang of 5.2 kg versus the bunch mass of the French type Essong of 9.5 kg has to be considered a genetic trait. The larger bunch mass attained in forest vs. bush/grass fallow may be due to higher soil fertility or other soil-borne advantages after forest clearing. The difference in bunch mass between forest and bush/grass fallow was larger in Essong than in Ebang which is likely to show the advantage of cultivars that form a large number of hands, bearing female flowers, thus representing a larger sink capacity for assimilates. Ebang forms usually 3–5 fruit hands and 4–8 fruits per hand and has a strong decline of fruits per hand along the peduncle. Essong forms 5–9 fruit hands and 7–14 fruits per hand without a decline in fruit number per hand for the first 2/3 of the hands. The cultivar Essong produced higher fresh bunch yields than Ebang in all but one of the treatments. The difference was dominantly caused by the higher bunch mass of Essong rather than an increased proportion of producing plants.

The fresh bunch yield of the plant crop reflects the capacity of the cultivar Essong to benefit from improved growing conditions. In the bush/grass fallow and when suckers had not been treated the cultivars did not differ in yield. The yield increase from bush/grass fallow to forest fallow was close to 200% in Ebang, yet 300% in Essong. Similarly, the yield increase due to hot-water treatment of the cultivar Ebang was 57% vs. 153% in the cultivar Essong. This indicates that under constrained conditions cultivar choice may be unimportant. If the system is intensified and investments need to be recovered it is more likely that French type cultivars producing large bunches such as Essong attain profitable yields.

Fresh bunch yields of the cultivar Essong in this on-farm trial did not reach levels attained in an on-station trial at another site after forest clearing (Hauser 2000) which ranged from 10.3 (control) to 27.7 Mg ha^{-1} (hot-water treated plus P and K fertilizer). In both trials the yield increment due to hot-water treatment and the combination of hot-water treatment plus fertilizer were similar at 51–56% and 138–169%, respectively. The yield increment due to fertilizer application alone was very low in the present trial with about + 7% vs. + 62% in the trial of Hauser (2000). No yield comparisons can be made for fertilizer application or the yields attained in the bush/grass fallow.

A major reason for the low yield increases due to fertilizer application in the present trial may be weed competition and the low weeding frequency at three weedings per year. The on-station trial by Hauser (2000) was thoroughly weeded whenever weeds reached about 70–80 cm height. Thus weeds were cut when they were still much lower, and probably had produced less biomass than those in the present trial where weeds would attain up to 1.5 m height before plots were weeded. This however, is how farmers manage their plantain fields. There are no data on plantains' response to weeding frequency.

In the degraded bush/grass fallow neither fertilizer nor hot-water treatment nor their combination increased bunch yields to the level attained in the forest even when neither hot-water treatment nor fertilizer were used (Figure 1). Soil nutrient and organic matter content were not related to the fresh bunch yield (not shown). Thus other factors than fertilizer and pest and disease control on suckers need to be considered in any future attempt to profitably produce plantains in bush/grass fallow land. Soil physical properties may play an important role because the root system of plantain is poorly developed with very little root length produced (Hauser unpublished). The diameter of primary roots is rather large at 3–6 mm, which may cause problems in the usually more compacted soils in bush/grass fallow (Nyobe 1998; Kotto-Same et al. 2000).

While the partially better soil chemical properties in the forest fallow might explain to some extent the higher yields, the lack of correlation between soil properties and yields indicates that other factors such as the treatments, specifically hot-water treatment or soil biological factors not investigated in this study overrode the effects of soil chemical properties.

The yield response patterns of plantain in this on-farm trial were the same as in an on-station trial and were as well found in a different cultivar and a different fallow type. The large yield gap between on-farm and on-station results indicates that on-farm yields can still be increased and thus it appears justified that the hot-water treatment and fertilizer application, pending economic analysis, be disseminated.

Conclusion

Sucker sanitation and fertilizer application are insufficient to raise plantain production in grass/bush fallow to levels attained in forest fallow. As such the use of already deforested land is not an option to reduce pressure on forest resources. However, this study did not include an economic component to assess profitability of plantain production in the different fallows and at various levels of input. At the time the trial was conducted and until recently application of fertilizer alone would have required a yield increase of 3 Mg ha^{-1} to balance the cost. Such a yield increase was only possible in combination with hot-water treatment. The volatile energy markets have caused fertilizer prices to increase and require higher yield increases today thus increasing farmers' risk. Treating suckers is inexpensive and independent of energy prices; a yield increase of 0.3 Mg ha^{-1} is sufficient to balance for the cost. Forest clearing is by far more expensive than bush and grass fallow clearing yet these costs have not been determined. Because plantain is the starting crop after forest clearing and followed by numerous cropping cycles, farmers probably do not allocate the clearing cost to the plantain. Until a full economic analysis is conducted and until the yield limiting factors in the deforested fallows are identified, it appears most appropriate for farmers to focus plantain production in forest fallow. Considering the yield increases realized here on-farm, the plantain production (output) of a household can be maintained and even increased while the area of cleared forest can be reduced to half of that usually required. In conclusion, the combination of hot-water treatment and fertilizer application can contribute to a reduction of pressure on forest resources.

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