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ADOPTION POTENTIAL OF HEDGEROW INTERCROPPING IN MAIZE-BASED CROPPING SYSTEMS IN THE HIGHLANDS OF WESTERN KENYA. 1. BACKGROUND AND AGRONOMIC EVALUATION

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SUMMARY

The biophysical performance of hedgerow intercropping for soil fertility inprovement was assessed in a farmer-participatory trial in western Kenya over three years. Farmers successfully established dense hedgerows (median 6680 trees ha^{-1} on plots of 790 m^2, but annual yields of hedgerow prunings of *Leucaena leucocephala* and *Calliandra calothyrsus* (1–4 t ha^{-1}), were low compared to potentials in the region (4–8 t ha^{-1}). The hedgerows reduced slopes from 7.2 to 4.5% within alleys ($p < 0.01$) but had no effect on grain yield over five seasons. Little of the variation in grain yield between hedgerow plots and control plots without hedgerows (adjusted $r^2 = 11\%$) and among control plots (adjusted $r^2 = 29\%$) could be accounted for by linear regression with measured agronomic and socio-economic variables. Fully researcher-managed trials are recommended for agronomic evaluation of complex agroforestry technologies.

INTRODUCTION

There is little scientific data on the performance of hedgerow intercropping (alley cropping, alley farming) for soil fertility improvement under farmer-managed conditions in the tropics, despite considerable on-station research (Kang *et al.*, 1990; Kang, 1993) and extension (Müller and Scherr, 1989; Carter, 1995). Potential difficulties in conducting on-farm trials with complex agroforestry technologies have been reviewed by Shepherd and Roger (1991). Earlier analyses of the adoption potential of hedgerow intercropping were based mainly on *ex ante* analysis of on-station trial results (Swinkels and Scherr, 1991). Few on-farm trials have been reported and these are mostly from sub-humid to humid areas of west Africa (Whittome, 1994). Even these trials had several limitations for the assessment of adoption potential: (1) targeting was inappropriate because farmers' priority problem was not usually low soil fertility; (2) farmers' participation was obtained through the provision of incentives, such as free fertilizer and improved crop material; and (3) there was limited monitoring to establish labour requirement, and crop and economic performance relative to existing systems (Whittome, 1994). Better farmer participation was obtained where soil fertility decline was perceived by farmers as a serious problem (Versteeg and Koudokpon, 1993). The limited adoption of hedgerow intercropping that has occurred has been for soil conservation on sloping land (particularly in the Asian/Pacific region) and for fodder production in intensive dairy systems, or because of indirect benefits provided by the projects themselves (Whittome, 1994: Carter, 1995).

This study aimed to assess the adoption potential of hedgerow intercropping, primarily for soil fertility improvement, in a subsistence-level crop-livestock farming system in the humid highlands of western Kenya. A secondary objective was to test the feasibility of evaluating treatment effects on yields with a complex agroforestry system in a farmer-participatory trial. Three years' results from a farmer-participatory trial are reported: the first paper gives the background and agronomic assessment, and a second paper reports economic and farmers' evaluation (Swinkels and Franzel, 1997).

MATERIALS AND METHODS

Study area and background

The study area included parts of Siaya, Kisumu and Vihiga Districts, located between lat 0°05′S and 0°10′N, and long 34°31′E to 34°40′E, chosen to represent humid areas of the food-crop land-use system of western Kenya which have high agricultural potential but where land has become nutrient-depleted (Shepherd *et al.*, 1996a). The population density ranges from 300 to >1000 persons km^{-2} in some areas. There are two cropping seasons: the long rains from March to July and the short rains from August to November, totalling 1500–1800 mm annual precipitation, with a mean annual temperature of 21°C. The landscape is undulating with average slopes of 2–8%, dominated by Acrisols, Ferralsols and Nitisols (Shepherd *et al.*, 1992).

Farmer selection and treatment design

Two to three farmers from twenty-nine farmer groups in the area participated in the trial; the groups were selected to represent the main variation in soils and ethnic groups in the area (Ohlsson *et al.*, 1992). The recommended prototype, which was developed with farmers, consisted of *Leucaena leucocephala* (leucaena), *L. diversifolia*, *Calliandra calothyrsus* (calliandra) or *Gliricidia sepium*, planted from inoculated seedlings, with 0.30 m between trees in contour-aligned rows about 4 m apart (Ohlsson *et al.*, 1992). Crops were planted close to the trees so that there was no loss of cropped area due to trees. The trial was started with 24 farmers from ten groups in August 1990, and with a further 29 farmers, including six additional groups, in February 1991. Farmers received regular advice from the project technicians on hedgerow management during each season throughout the reported period, but farmers made all crop and tree management decisions.

Trial design and measurements

Main trial. The trial design consisted of a control plot without hedges and an adjacent plot with hedges on each farm. The *L. leucocephala* seedlings were a mixture of Hengchun, Kisumu, Gede, Siakago and Baobab provenances obtained from mother trees at the Maseno Agroforestry Centre (29 farms), *C. calothyrsus* was of Guatemala provenance (18 farms), *L. diversifolia* was of Veracruz (Mexico) provenance (4 farms) and *G. sepium* was established from cuttings from a local source (2 farms). The 1990 plantings were all of *L. leucocephala*. The seedlings were incoculated with compatible rhizobia in polythene tubes in a nursery before being delivered to the farms.

On each tree plot, the number of trees planted, the number surviving at six months, and the causes of plant death were recorded. On a subset of 12 farms of *Leucaena* spp. and 12 of *C. calothyrsus,* tree height and basal shoot diameter at one and six months after planting and at the time of the first cut, and tree biomass and nutrient yields at each cut for the first two years after planting were recorded. Oven-dry (60°C) tree biomass was measured on four systematically located 2-m lengths of hedge from each plot and N, P, K, Ca and Mg concentrations in leaf, twig and woody stem components were determined on subsamples, using wet Kjeldahl oxidation. The total length of hedge and the plot size were used to calculate tree biomass and nutrient yields per hectare.

Crop harvest yields were measured on the whole area of test and control plots in five consecutive seasons from the short rains in 1990 on the 41 farms where annual crops were grown and the trial maintained. The total produce of maize cobs and pods of any intercrops from each plot were weighed and subsamples taken to determine oven-dry grain weight. Farmers estimates of numbers of green maize cobs harvested earlier in the season were converted to dry grain weight on the basis of average cob weights. Crop plant populations were estimated from quadrat counts, and the incidence of pests, weeds, diseases, and other causes of crop damage (maize streak virus, *Striga hermonthica,* termites, browsing, hail) were scored on each plot. Data on the use of labour and other inputs were collected for each plot (Swinkels and Franzel, 1997). Plot sizes were varied seasonally by farmers and so were measured each season.

Soil properties were determined in each plot (Shepherd *et al.*, 1996a). Average slopes were measured on all farms using a clinometer. On eight of the steeper farms, the average slope of the hedgerow plot and the slope within each alley were determined in October 1994 using a surveying level. Daily rainfall was recorded at Maseno Agroforestry Research Centre (lat 0°0′N, long 34°35′E).

In 1992–93, a census of households participating in the trial was conducted using a structured interview schedule (David and Swinkels, 1994) to characterize their social and economic situation.

Competition study. The study aimed to assess the degree of competition between the hedges and the adjacent maize rows. In the long rains of 1993 hybrid maize

(H512) was planted by the researchers in rows 75 cm apart in the test and control plots on 12 uniformly-managed farms. The average grain and stover yields (oven-dry weight basis) of the two outside rows (the rows next to the hedge) were compared with the average yields of the inside rows in the centre of each of three alleys per farm, and the test-plot yields were also compared with those measured in the control plots.

Maize fertilizer trial. This study aimed to confirm maize yield responsiveness to applied nutrients and tree prunings. The study was conducted on the same 12 farms and in the same season as the competition study. Six unreplicated treatments were applied to H512 maize in the control plots of the 12 farms: factorial combinations of 0 or 50 kg P ha^{-1} and 0 or 120 kg N ha^{-1}, compared with single basal applications of *L. leucocephala* prunings (leaf plus twig, 1.9 g N and 0.09 g P kg^{-1} at 2.5 or 5.0 t dry matter (DM) ha^{-1}). P was applied as single superphosphate and N as urea. The oven-dry weights of maize grain and stover, and weeds were determined from a net plot of 9 m^2.

Hedge fertilizer trial. This study aimed to test the response of hedge biomass production to N and P applications. The four fertilizer treatments used in the maize fertilizer trial were applied to 4-m lengths of hedge on 12 farms of *L. leucocephala* and 12 farms of *C. calothyrsus*. The fertilizers were incorporated into the topsoil in a band 50 cm wide on both sides of the hedge. The N fertilizer was applied in three equal applications in March, April and August 1993. Tree biomass was measured in net plots (2 m) for five consecutive cuts, from the second cut of the long rains in 1993 to the second cut of the long rains in 1994, using the same procedure as used in the main trial.

Statistical analysis

Treatment effects were assessed by analysis of variance using farms as randomized blocks. Relationships between the measured variables were examined graphically and by multiple regression analysis, using Statistical Analysis Systems procedures (SAS, 1990).

RESULTS AND DISCUSSION

Farm characteristics

A wide range of farmer characteristics was obtained in the sample (Table 1). Eleven of the 56 participating farmers dropped out of the trial within the first year (Swinkels and Franzel, 1997) but in other respects the participatory approach was successful in maintaining farmers' interest in the trial.

Seasonal rainfall characteristics

The seasonal total rainfall at Maseno for each of the seven seasons from the

Table 1. *Characteristics of 45 farmers participating in the hedgerow intercropping trial*

Variable		Minimum	Median	Maximum	Proportion (%)
Farm size, all parcels (ha)		0.1	1.3	6.1	—
Household size (members)		2	6	15	—
Labour : land ratio (adult equivalent workers ha^{-1})		0.6	2.2	23.6	—
Farm first cultivated (year)		1935	1977	1991	—
Ethnic group:	Luhya				22
	Luo				78
Household type:	male				72
	female *de jure*				13
	female *de facto*				15
Age of household head (years):	<40				24
	40–60				52
	>60				24
Education of household head:	< primary				19
	primary				59
	> primary				22
Wealth category:	< average				26
	average				67
	> average				7
Off-farm income (one or both partners)					82
Use of hired labour					87
Ownership of cows					80
Ownership of improved breed of cows					6

short rains 1990 did not differ by more than 25% from the long-term average values (895 mm in long rains and 774 mm in short rains in 1960–1993).

Tree establishment and early growth

The size of plots planted with hedges ranged from 270 to 2010 m^2 with a median of 790 m^2 ($n = 42$). Tree density, which ranged from 3660 to 10 040 ha^{-1} with a median of 6680 trees ha^{-1}, was negatively correlated with plot size ($r = -0.45$, $p < 0.01$). This indicated that the potential benefits of the technology would decrease with increasing plot size. The proportion of the originally planted trees surviving at six months after planting (MAP) ranged from 0.33 to 1.00 with a median of 0.91. Termite damage was observed to be the primary cause of tree mortality on 30 farms, whereas other causes were important on only a few farms: moles, 4; drought, 3; uprooting, 1; erosion, 1; and fire, 1. Browsing, mostly by Kirk's dik-dik (*Madoqua kirki*), occurred on 10 farms, primarily those near fallow land.

Survival was not related to browsing, but there was a higher frequency of low survival rates in leucaena (40% farms had $<80\%$ survival, $n = 25$ farms) than in calliandra (6% farms had $<80\%$ survival, $n = 17$). The frequency of termites as the main cause of damage was similar for the two species (68% leucaena, 76% calliandra), but the survival differences could have been due to differences in rainfall during the first two months after planting. This was lower (302 mm) in the short rains of 1990 when most ($n = 22$) of the leucaena was planted than in the long rains of 1991 (537 mm) when all of the calliandra was planted.

At six MAP, median tree height was 97 cm (range 34–140) for leucaena (12 farms) and 152 cm (range 90–196) for calliandra (12 farms), while median stem basal diameter was 1.4 cm (range 1.0–1.8) and 1.5 cm (range 0.8–2.1) respectively. The median early growth rates were substantially lower (about 40%) than those obtained with the same provenances in researcher-managed experiments at the Maseno Agroforestry Research Centre. In these experiments *L. leucocephala* had a height of 180–200 cm and a root collar diameter of 1.7–2.5 cm and *C. calothyrsus* had a height of 270 cm and root collar diameter of 2.3 cm at six MAP (Heineman *et al.*, 1990). However, trees in the on-station experiments (topsoil pH water = 5.1) received 25 g diammonium phosphate per tree at transplanting and were established with well-weeded and P-fertilized beans for the first two seasons.

Tree yield and nutrient content

Farmers cut the hedges between four and seven times during the two years' monitoring of hedge biomass on 24 farms and crops were not grown and the hedges were not pruned in seasons when the plots were fallowed. There was no significant effect of species, provenance, season or year on tree total biomass yield and DM partitioning ($p > 0.05$). However, total biomass was significantly greater ($p < 0.001$) at the first cut (1.68 t ha^{-1}) than at the second cut (0.74 t ha^{-1}) in the season. Woody stem comprised 0.33 of the total biomass at the first cut but only 0.04 at the second cut, reflecting the younger growth at the second cut. These results compare with those of Balasubramanian and Sekayange (1991), who used the same two species in a similar environment, and found woody stem fractions of about 0.4 at the first cut but no woody biomass at the second cut in a season. Tree biomass yield following a fallow season, in which trees were not cut (five occurrences on the 24 farms), was 2.1 times the mean biomass yield from continuous cutting on the same farms. After a fallow season, stem comprised 0.39 biomass compared with 0.12 for continuous cutting.

On the farms the annual amount of biomass returned to the soil ranged from 1.2 to 4.3 t ha^{-1} (Table 2) and was below on-station levels measured over the same growth phase (about 4.4 t ha^{-1} for leucaena (Hengchun) at a spacing of 3.75 × 0.25 m, and 7.3 t ha^{-1} for leucaena (Hengchun) and 10.8 t ha^{-1} for calliandra (Guatemala) both at a spacing of 2.8 × 0.25 m (Heineman *et al.*, 1990; Otieno *et al.*, 1991)). In experiments in the sub-humid and humid tropics with the same species and management, maximum annual yields of prunings were 4–8 t ha^{-1} (Balasubramanian and Sekayange, 1991; Kang, 1993).

The amounts of nutrients returned in prunings were correspondingly low (Table 2) but on all farms the amounts were significant in relation to crop requirements. The maximum annual amounts of nutrient exported in stems were 20 kg N and 2 kg P ha^{-1}, which were agronomically significant, although median values were low (Table 2). Concentrations of N, P, K, Ca and Mg in leaves were significantly higher in leucaena than calliandra, especially for K and Ca (Table

Table 2. *Average annual dry biomass yield ($t\ ha^{-1}$) and nutrient yield ($kg\ ha^{-1}$) of hedgerow prunings and stem for the first two years of production on 24 farms*

	Prunings			Stem		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Biomass	1.16	2.40	4.29	0.15	1.05	2.53
N	34.0	59.7	125.8	0.6	6.4	17.4
P	1.17	3.21	5.65	0.09	0.67	1.86
K	10.7	25.2	59.9	1.3	9.1	24.1
Ca	8.9	25.5	61.0	0.3	2.5	6.7
Mg	2.3	6.1	13.4	0.2	0.8	2.7

3). N, P and K concentrations in leaves and twigs were higher at the second than at the first cut in the season (Table 3), reflecting the younger age of the plant material at the second cut. Median leaf nutrient concentrations in leucaena (Table 3) compared with the average values of 38 g N, 2.0 g P, 21 g K, 13 g Ca and 3.3 g Mg kg^{-1} found by Budelman (1989) in his survey of the literature.

Total harvested biomass among farms was positively correlated with the concentration of stem N (adjusted $r = 0.66$) in calliandra, and with leaf Ca ($r = 0.66$) in leucaena. However, in the hedge fertilizer trial, the N and P treatment means had little effect on hedge biomass; the total biomass over five cuts did not differ by more than 8% from the overall mean in either species and

Table 3. *Effect of species and time of cutting on nutrient concentrations ($g\ kg^{-1}$) in the leaf, twig and stem components of leucaena* (Leucaena leucocephala) *and calliandra* (Calliandra calothyrsus)

		Leucaena	Calliandra	First cut	Second cut	s.e.d.
Leaf	N	32.7	37.1***	31.3	38.6***	0.985
	P	1.42	1.65*	1.35	1.72***	0.0935
	K	9.4	15.3***	11.4	13.2***	0.53
	Ca	11.3	15.0***	14.0	12.3	0.90
	Mg	2.43	3.24***	2.87	2.80	0.165
Twig	N	13.7	12.3*	10.8	15.2***	0.65
	P	1.03	0.95	0.84	1.14***	0.086
	K	14.3	13.3	11.9	15.8***	0.78
	Ca	3.86	4.17	4.18	3.85	0.243
	Mg	1.68	2.02*	1.85	1.86	0.141
Stem	N	6.44	8.06*	—	—	0.793
	P	0.60	0.72	—	—	0.077
	K	0.84	0.99	—	—	0.802
	Ca	2.24	2.53*	—	—	0.131
	Mg	0.76	1.24***	—	—	0.114

*, **, *** denote that mean values differ significantly at $p < 0.05$, < 0.01, or < 0.001, respectively; species × cut interactions were not significant at $p < 0.10$.

there were no interesting relationships between biomass and soil properties. In a pot experiment with soils from twelve of the same farms, growth of leucaena was strongly related to soil pH (range 5.0–6.7 in water) and infection levels of arbuscular mycorrhizal fungi at 25 days after planting. There were also strong growth responses to applications of P and manure at low infection levels (Shepherd *et al.*, 1996b). The lower early growth rates on-farm compared with on-station suggested that the competition effects between crops and weeds during early establishment could also be an important cause of the variation in tree growth on farms. Therefore, subsequent work should examine the field responses of these tree species to early competition, nutrition and arbuscular mycorrhizal infection levels.

The growth of leucaena was affected by an infestation of the psyllid *Heteropsylla cubana* from March 1993 onwards. Total biomass over the five cuts was 590 g m^{-1} of hedge (range 90–810) in leucaena compared with 1850 g m^{-1} (range 1000–2860) in calliandra; before 1993 there was no difference in yields between the two species. It was concluded that the potential effects of leucaena on soil fertility are likely to be limited as long as the psyllid infestation persists.

Terracing effect of hedges

Average slopes ranged from 1 to 13% with a median of 5.8% (44 farms). The hedgerows had a significant terracing effect; the mean slope within alleys was 4.5% compared with 7.2% over the length of the hedgerow plots ($p < 0.01$, 8 farms).

Crop yields

Maize fertilizer trial. In the 1993 maize fertilizer trial, because of theft or extreme variability within plots, grain yields were analysed from only 8 farms and stover yield from 11 of the 12 original farms. Despite the presence of *Striga hermonthica* and maize streak virus, P or N alone increased grain yield from 0.7 to 1.2 or 1.1 t ha^{-1} ($p < 0.01$), but there was a significant N × P interaction and with both nutrients the yield was 2.7 t ha^{-1} ($p < 0.01$). There was no difference in yield between the two pruning application rates, which on average increased grain yield to 1.3 t ha^{-1} ($p < 0.05$). The prunings, which supplied 48–95 kg N ha^{-1} but only 2–4 kg P ha^{-1}, were no less efficient than N fertilizer alone. The overall trends were similar for the stover yields which increased from 1.1 t ha^{-1} without fertilizer to 1.5 t ha^{-1} with mulch, and 2.8 t ha^{-1} with both N and P. The results demonstrated that maize, when well-managed on the trial farms, was responsive to moderate applications of P and N fertilizers and to leucaena prunings.

Competition study. Differences between farms in the yield of maize rows adjacent to the hedge and those in the centre of the alley were not significant and were as little as 10% of the overall mean for grain (0.90 t ha^{-1}, 8 farms) and 4% of the mean for stover (1.02 t ha^{-1}, 11 farms). Tree species had no effect on the differences (based on 5 farms each for leucaena and calliandra). Furthermore, mean grain and stover yields for the fertilizer trial control plot; were not significantly different ($p > 0.05$) from those measured in the adjacent hedgerow plot; the mean difference between farms was less than 25% of the mean for grain yield (0.8 t ha^{-1}, 8 farms), and less than 3% of the mean for stover yield (1.1 t ha^{-1}, 11 farms). Thus, there was little evidence for any net effect of the hedges on maize yield when the plots were managed by researchers.

Main trial. Farmers grew a wide range of crop mixtures and fallows in the test control plots, making it difficult to evaluate the effects of the hedgerows on yields. For example, in the long rains of 1992, out of 86 plots, 68 had maize, 6 sorghum, 39 beans, 18 groundnuts, 16 weedy fallow, 6 sorghums, 2 cowpeas, 1 sweet potatoes, and 1 cassava. Farms where maize was grown as the main crop in both plots, either as a sole crop or with grain intercrops, were selected for analysis of yields in each season. There was no significant difference in mean grain yields (total grain biomass from sum of maize and intercrop grain dry weights) between the hedgerow and the control plots in any individual season (Table 4). Averaged over five seasons, mean grain yields were 16% lower in the hedgerow plots than the control plots but the significance of this difference was marginal ($p = 0.05$). The lack of evidence for an effect of the hedges on yield in the researcher-managed competition study suggested that the difference was due to variation in farmer management between the two plots.

In the regression models selected, soil and management variables were hypothesized to account for the variation in control plot grain yields and the difference in grain yield between the hedgerow and control plots. A strong dependence of maize yields on total soil N, pH and mean annual temperature has been demonstrated in researcher-managed trials in Kenya (Smaling and Janssen, 1993). The available P in the topsoil was below the critical limit for maize (Olsen P < 7 mg kg^{-1}, Okalebo, 1987) on 26 of the 31 farms, and the maize

Table 4. *Untransformed (kg ha^{-1}) and transformed (log$_e$) mean grain yields in control and hedgerow plots in the short rains 1990 (S90), long rains 1991 (L91), short rains 1991 (S91), long rains 1992 (L92) and short rains 1992 (S92) and for the mean of the five seasons*

		Grain yield		Transformed grain yield		
Season	Number of farms	Control	Hedgerows	Control	Hedgerows	s.e.d.
S90	12	1200	1260	6.93	6.96	0.136
L91	32	1320	1170	6.97	6.84	0.103
S91	28	820	660	6.47	6.30	0.144
L92	28	1530	1370	7.16	7.08	0.118
S92	25	1110	1120	6.67	6.78	0.108
Mean†	41	1170	980	6.92	6.77	0.078*

† Mean = mean of all farm × season combinations; *$p = 0.05$

fertilizer trial also confirmed the responsiveness of maize to applied P and N. Total N and available P concentrations in the topsoil were also assumed to reflect variation in manuring history, which, on the basis of discussions with farmers, was hypothesized to be an important source of yield variation. Topsoils were only weakly acid (5.0–7.0, median = 6.0, $n = 31$) and aluminium saturation of the exchangeable cation exchange capacity was too low (range = 0–27%, median = 0, $n = 31$) to have affected maize growth. Total cash spent per plot on purchased seed, fertilizer and labour (Swinkels and Franzel, 1997) was taken to reflect variation in farmers' level of crop management.

The models fitted to the data for the average of four seasons (1991 and 1992, $n = 25$) were:

$$Y_c = -131\ (729) + 479\ (304)\ N_c + 216^{*}\ (116) \log_e P_c + 81\ (132) \log_e I_c + 172\ (153)\ M_c$$

$$\text{adjusted } r^2 = 0.29$$

$$Y_d = -50\ (696) - 463\ (339)\ N_m + 149\ (185) \log_e P_m + 151\ (126) \log_e I_m - 302\ (195)\ M_m + 26\ (29)\ P_d + 14^{**}\ (6.5)\ I_d - 164\ (313)\ M_d$$

$$\text{adjusted } r^2 = 0.11$$

where Y = grain yield (kg ha^{-1}); N = topsoil N concentration (mg kg^{-1}); P = topsoil available P concentration (mg kg^{-1}); I = purchased inputs (US$ ha^{-1}; 1$ = 31 Kenya Shillings); M = manure application (t DM ha^{-1}); subscript c denotes values for control plots; subscript m denotes mean of control and hedgerow plots; subscript d denotes the difference between hedgerow and control plots; * denotes $p < 0.10$, ** $p < 0.05$; and numbers in parentheses are standard errors. Ranges of the independent variables were as follows: N_c (0.8, 2.5); P_c (1, 42); I_c (9, 219); M_c (0, 3.7); N_m (0.8, 2.3); P_m (1, 34); I_m (7, 232); M_m (0, 2.8); P_d (-16, 6); I_d (-63, 26); and M_d (-1.9, 0.8).

Only the model for Y_c explained a statistically significant amount of the variation ($p < 0.05$; range in Y_c for range in independent variables was 0.3–2.8 t ha^{-1}) and neither model accounted for much of the yield variation. However, the coefficients suggest some influence of available P on control plot yields and of the difference in purchased inputs on the size of the yield difference between plots. Including the N × P interaction in the models neither improved the regression models consistently nor led to a clearer understanding of the results.

The models fitted to the individual season data (Tables 5 and 6) generally accounted for a low proportion of the variation in yields and in the plot-to-plot yield differences among farms. For the effect on control plot yields, a different parameter was significant ($p < 0.1$) in each season, although manure application was significant in the two seasons in which it was applied (Table 5). There was a trend of consistently large positive values for the soil N parameter (a) in each season. For the yield differences between plots, there were no meaningful trends in the parameter values among seasons. The large ranges in the soil and manage-

Table 5. *Values of intercepts and regression coefficients relating grain yield (Y_c, kg ha^{-1}) to topsoil nitrogen concentration (N_c, g kg^{-1}), topsoil available phosphorus concentration (P_c, mg kg^{-1}), purchased inputs (I_c, US\$ ha^{-1}) and manure application rate (M_c, t ha^{-1}) in the control plots in the long rains 1991 (L91), short rains 1991 (S91), long rains 1992 (L92) and short rains 1992 (S92)*

	Season			
Parameter	L91	S91	L92	S92
	$Y_c = \text{intercept} + aN_c + b\log_e P_c + c\log_e I_c + dM_c$			
n†	20	17	17	14
Intercept	720 (910)	−560 (610)	1200 (1210)	−940 (1370)
a	900* (430)	512 (310)	380 (470)	520 (530)
b	8 (190)	24 (110)	110 (180)	590** (190)
c	−230 (180)	190* (190)	−130 (240)	230 (230)
d	180** (90)	—	400* (200)	—
adjusted r^2	0.32	0.13	0.31	0.48

†n = number of farms; *$p < 0.10$; **$p < 0.05$; values in parentheses are standard errors.

Table 6. *Values of intercept and regression coefficients relating the difference in grain yield between hedgerow and control plots (Y_d, kg ha^{-1}) to mean topsoil N concentration (N_m, g kg^{-1}), mean topsoil available P concentration (P_m, mg kg^{-1}), difference in topsoil available P (P_d, mg kg^{-1}), mean purchased inputs (I_m, US\$ ha^{-1}), difference in purchased inputs (I_d, US\$ ha^{-1}), mean manure rate (M_m, t ha^{-1}), and difference in manure rate (M_d, t ha^{-1}) between hedgerow and control plots in the long rains 1991 (L91), short rains 1991 (S91), long rains 1992 (L92) and short rains 1992 (S92)*

	Season			
Parameter	L91	S91	L92	S92
	$Y_d = \text{intercept} + aN_m + b\log_e P_m + cP_d + d\log_e I_m + eI_d + f\mathrm{M}_\mathrm{m} + gM_d$			
n†	20	17	17	14
Intercept	−770 (1090)	400 (410)	−1300 (1950)	130 (1330)
a	−480 (560)	−350 (240)	340 (830)	−500 (640)
b	−370 (360)	130 (130)	15 (460)	250 (310)
c	−54 (70)	12 (20)	11 (58)	30 (42)
d	420* (210)	−62 (68)	240 (390)	110 (230)
e	14* (7.4)	4.9 (2.5)	2.5 (21)	−0.9 (9.6)
f	−100 (140)	—	−290 (420)	—
g	−100 (290)	—	−160 (540)	—
Adjusted r^2	0.27	0.14	−0.48	−0.20

†n = number of farms; *$p < 0.10$; values in parentheses are standard errors.

ment variables between plots illustrate the difficulties in making valid comparisons of treatments in this trial.

Exploratory analysis with other measured variables (mean of four seasons) indicated possible dependence of the control plot yields on topsoil exchangeable K ($r = 0.63$, $p < 0.001$, $n = 25$), topsoil bulk density ($r = -0.53$, $p < 0.01$, $n = 25$), and household type (male-head = 1, female-head = 2; $r = -0.46$, $p < 0.01$, $n = 41$). Grain yield difference (Y_d) was correlated with mean seasonal application rates of hedge biomass ($r = 0.50$, $p < 0.05$, $n = 23$); mean topsoil exchangeable K ($r = -0.47$, $p < 0.05$, $n = 25$), and the difference in total labour hours for land preparation and weeding ($r = 0.40$, $p < 0.01$, $n = 41$). There were no other interesting relationships in the individual seasons. Apparently, variation in yield among plots and farms was determined by a wide range of biophysical and socio-economic factors and could not be adequately explained by the measured variables within the limitations of the sample size.

Value of trial

The results support many of the arguments put forward by Shepherd and Roger (1991) concerning the difficulty in drawing useful conclusions on treatment effects in farmer-managed trials with complex agroforestry technologies. Despite considerable investment in monitoring a wide range of biophysical and socio-economic variables in the trial, they explained little of the variation in yields between treatment and control plots and among farms. Furthermore, the large number of crop permutations and hedge management practices limited the number of observations available for multiple regression analysis of treatment effects on yields. Therefore, we recommend fully researcher-managed trials for agronomic evaluation of complex agroforestry technologies. Economic and farmers' evaluation require different methods (Swinkels and Franzel, 1997).

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