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Maize-mucuna (*Mucuna pruriens* (L.) DC) relay intercropping in the lowland tropics of Timor-Leste

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ABSTRACT

Timor-Leste is a small predominantly agrarian society based on subsistence agriculture with maize as the key staple crop and food. Maize cropping is predominantly shifting in a slash and burn system with weed management and soil fertility key issues to farmers. An increasing population and farmer reluctance to use inorganic fertilizer drive the need to find improved cropping systems. This experimental series from 2007 to 2012 was designed to evaluate relay-sown intercropped mucuna (*Mucuna pruriens* (L.) DC var. *utilis*) with maize as a low-input legume intercropping system for its potential in the management of weeds and soil fertility. Factors investigated include legume species, optimum sowing time for inter-crop with maize, comparison of maize sown sole v. maize intercropped with mucuna, weeding regimes, and the effects of crop sequences with mucuna. Delaying mucuna sowing time to approximately one month after maize planting is particularly critical. Comparing continuous sole-cropped maize with maize relay-sown with mucuna, intercropping significantly reduced the weed burden on maize – often completely eliminating weeds. In the South of the country over five rotational cycles the percentage maize yield advantage of cropping with mucuna v. sole-cropping was 132%, lifting maize yield from a mean of 0.94 t ha^{-1} from successive mono-cropped maize to a mean of 2.19 t ha^{-1} with mucuna. Participatory research with farmers is now required to encourage Timorese farmers to (re-)adopt this agronomic system in appropriate parts of the country.

1. Introduction

Timor-Leste is a small, young tropical country with a rapidly growing and primarily rural population. Farmers in Timor-Leste have developed agricultural systems based mainly on shifting cultivation on the coastal plain and upland areas. Maize (*Zea mays* L.) is the key staple food and crop complemented by the root crops sweet potato (*Ipomoea batatas* L.) and cassava (*Manihot esculenta* Crantz) and rice (*Oryza sativa* L.) (da Costa et al., 2013). Traditionally soil management consists of the continual use of land for crops during a short period of two–five years followed by its abandonment for a long period of up to 20 years. A rural household typically crops 0.5–0.8 ha at any one time. With an increasing population and pressure on the land, the fallow period is reducing, and farmers are also reluctant to use inorganic fertilizer to maintain fertility, primarily from their belief that added chemicals are detrimental to soil, crop and human health, and also from the expense. The climate in Timor-Leste is predicted to become about 1.5 °C warmer on average by 2050, further stressing food security, and about 10% wetter (Molyneux et al., 2012). Additionally, labour is either expensive or scarce.

The pattern seen in Timor-Leste of soil fertility reducing with land pressure is very common throughout the humid tropics and has spurred the search for improved fallows with legumes in many places. In parts of Africa and Central America improved fallowing with legumes has gained popularity. Among legumes, mucuna (*Mucuna pruriens* (L.) DC var. *utilis*) – sometimes known as velvet bean – has often been chosen as a green manure crop for its exceptional vigour. It consistently shows superior agronomic performance compared to other annual legumes, having green forage yields of up to 15 t ha^{-1} per season and seed production ranging from 200 to 2000 kg ha^{-1} (Wulijarni-Soetjipto and Maligalig, 1997).

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Its abundant biomass production contributes to make mucuna able to reclaim land infested with weeds, including those dominated by spear grass (*Imperata cylindrica* (L.) Raeuschel) (Wulijarni-Soetjipto and Maligalig, 1997).

Mucuna is reported to grow in an annual rainfall ranging from 400 to 3000 mm, but in West Africa and Honduras it is successful in areas with long rainy seasons – similar to the lowland south coast of Timor-Leste. It has a shallow root system and is only moderately resistant to drought. Mucuna grows best at an average annual temperature of 19–27 °C and prefers well-drained sandy and clay soils with a pH of 5–6.5, but it can also grow vigorously on acidic sandy soils (Wulijarni-Soetjipto and Maligalig, 1997). Despite its fast growth rate, mucuna presents a low risk of becoming invasive in Timor-Leste as its leaves are highly palatable for feral and domestic animals, particularly goats.

Tarawali et al. (1999) and Douthwaite et al. (2002) in studying the dissemination of mucuna cropping in West Africa highlighted the lessons learnt while promoting the technology to small-scale producers. Mucuna was popularized in the Mono Province of southwestern Benin in the period 1988–1992. By 1996 the number of testers of the innovation throughout Benin was 10,000 farmers. Suppression of the weed spear grass was perceived as the main benefit of mucuna fallows. Recommendations to increase the adoption of legume fallowing include the use of a participatory approach in problem identification, highlighting the immediate gains to growers, optimization of the multiple benefits of cover crops, management of the improved system, promotional strategies, and appropriate policies.

In eastern Uganda researchers worked with farmers to develop alternatives for soil management using mucuna and other legumes as green manures in short-term fallows (Fischler and Wortmann, 1999). Their participatory research was part of a community-based approach to improve systems. Grain yields of maize following a one-season fallow with Mucuna were 60% higher as compared with maize following maize. Mucuna and lablab (*Lablab purpureus* (L.) Sweet were successfully produced by inter-sowing into maize three weeks after sowing maize, although the yields of the associated maize crop were reduced by 24–28%. Farmers independently experimented on how these species can be integrated into banana (*Musa* spp.), coffee (*Coffea canephora* Pierre ex Froehner), sweet potato, and cassava production systems. Farmers reported that the beneficial effects of the green manures included higher yields of food crops; weed suppression; improved soil fertility, soil moisture, and soil tilth; and erosion control. Mucuna and lablab were preferred because of reduced labour requirements and increased net benefits compared with continuous cropping. Farmer participation in the green manure research resulted in efficient generation and adaptation of green manure technology now being promoted in eastern and central Uganda.

In northern Honduras in response to rising land pressure, farmers developed and diffused from farmer-to-farmer a maize cropping system using mucuna as a short-term fallow (Buckles and Triomphe, 1999). Under high rainfall with a bimodal distribution, two rainfed cropping cycles are completed annually with the first season dedicated to the production of mucuna and the second season dedicated to maize. Buckles and Triomphe (1999) recorded maize yields in fields with continuous rotation of mucuna as on average double those obtained without mucuna. The mucuna system was more profitable than the existing alternative bush-fallow system due to higher returns to land and labour resulting from higher maize yields, lower weeding and land preparation costs, and reduced risk of drought stress.

In Timor-Leste mucuna is known by the local name *Lehe*, while the wild form (*M. pruriens* var. *pruriens*) known locally as *Karalehe* (literally 'itchy velvet bean') grows in many areas of the island, but its skin irritating properties make it unsuitable for cultivation. A study of *Lehe* started in 2003 by UNTL/Oxfam provided evidence that mucuna was formerly intercropped with maize in Timor-Leste as a weed control and soil fertilizer, as well as a food crop at least as long ago as the Portuguese era. However, its cultivation was reduced as the seed became largely unavailable when farmers fled the Indonesian occupation, and has returned only relatively recently (Vidal and Williams, 2012). Today in most of the country mucuna is only grown as a minor source of food, often sown at the base of a tree or fence. Although the seeds contain the psychoactive drug L-dopa, the bean becomes edible on boiling followed by soaking in water for 1–2 days with frequent water changes to remove the toxins (Wulijarni-Soetjipto and Maligalig, 1997). Its other benefits, when grown as a mulch crop, are now largely unknown. Weed problems and the need for legume fallows, together with an awareness of the utility of mucuna to small-holders elsewhere in the tropics, prompted its agronomic evaluation in maize-based systems in Timor-Leste. We hypothesized that Mucuna offers advantages to low input cropping of maize in Timor-Leste on the basis of its potential for weed control and soil fertility improvement elsewhere. To test this we designed a series of trials on-station to explore legume intercropping options which included species comparison, exploration of optimum legume sowing time when intercropped with maize, comparison of maize sown sole v. maize intercropped with mucuna, and weeding regimes to gain initial agronomic management information on mucuna in TL. With confidence of the value of mucuna in TL, we then initiated long-term trials on the effects of crop sequences on-station – it being impossible to undertake controlled long-term trials on-farm in TL.

2. Materials and methods

In the period 2007–2012 a series of trials with mucuna were conducted at four sites in Timor-Leste on a range of different factors summarized in Table 1.

2.1. Trial 1: UNTL agriculture faculty, Hera 2007

The research was conducted as part of a student's (L.D.A.) final year study at the Agriculture Faculty farm (Hera), National University of Timor-Leste (UNTL) in the North of the country (8°32′ S, 125°41′ E; 30 m above sea level (asl)) in tropofluvent soil (map unit BC1 in Garcia and Cardoso, 1978). The study was to define the best species and sowing time to use as an inter-crop, placing an emphasis on maize yields. Sowing time treatments of legume inter-crop when intercropped with maize were (1) sowing maize and legume at the same time, (2) sowing legume three weeks after maize and (3) sowing legume five weeks after maize (Table 1). The legume intercrop species were (1) Mucuna, (2) Sword bean (*Canavalia gladiata* (L.) DC) and (3) Jack bean (*Canavalia ensiformis* (L.) DC). The control was sole-cropped maize (without legume). The trial was in a randomized block design with three replications. Maize planting was in January 2007 into plots sized 25 m^2, and all maize was harvested in May 2007. Plots were kept weed-free and received no fertilizer. At harvest, maize yield was recorded for grain – in this trial and hereafter unless specifically mentioned as cob yield – from selected plants in each plot.

2.2. Trial 2 at Betano in the wet and dry seasons of 2007

A trial to evaluate the effects of sowing mucuna in maize was conducted at Betano Research Station in the South of the country (9°16′ S, 125°68′ E; 3 m asl) in Usifluvent soil (map unit Atc in Garcia and Cardoso, 1978) with pH 7.5 (Howeler et al., 2003) over the wet and dry seasons in 2007. The initial trial comprised three factors (Table 1): (1) maize sown sole v. maize intercropped with

Table 1
Experimental summary listing trials with their location and seasons, sowing date, total rainfall during the cropping season, number of replications (Rep), and factors (and levels) investigated.

Trial #	Location	Season/year	Sowing date	Rain (mm)[a]	Rep	Factors and levels investigated
1	UNTL Farm, Hera, Dili	Wet 2007	January 2007	~600	3	- Legume inter-crops: (1) Mucuna, (2) Sword bean and (3) Jack bean - Sowing time when intercropped with maize: (1) Legume sown with maize, (2) Legume sown 3 weeks after maize, (3) Legume sown 5 weeks after maize
2	Betano Station, Manufahi	Wet 2007	16/01/07	403	3	- Maize sown sole v. intercropped with mucuna - Weeding regimes: Weeded 1, 2 & 3 times - Maize variety: Local white vs. introduced Harare 52
2		Dry 2007	04/06/07	984	3	- Crop sequences: (1) Mucuna/maize grown together two times in succession; (2) Mucuna/maize followed by maize alone; and (3) maize grown as a monoculture two times in succession - Weeding regimes: Weeded 1, 2 & 3 times
3	Corluli Station, Bobonaro	Wet 2007–2008	23/11/07	602	3	- Sowing time when intercropped with maize: (1) Mucuna sown with maize, (2) Mucuna sown 2 weeks after maize, (3) Mucuna sown 4 weeks after maize - Weeding regimes: Weeded 1 & 2 times
4	Betano Station	Wet 2008–2009	December 2008	670	3	Treatments in Trials 4 and 5 No.treatment/factortreatment
4		Wet 2009–2010	December 2009	400	3	Tr'ctr Glyph Hand prepMucuna
4		Wet 2010–2011	20/12/10	500	3	1+−−−Tillage (mechanical)
4		Dry 2011	16/06/11	301	3	2−+−−Glyphosate
4		Wet 2011–2012	15/12/11	424	3	3[b]−−+−Hand preparation
4		Dry 2012	30/05/12	156	3	4+−−+Combination Tillage/Mucuna
5	Loes Station	Wet 2010–2011	16/12/10	406	4	5−+−+Combi. Glyphosate/Mucuna
5		Dry 2011	27/06/11	307	4	6−−++Combi. Hand prep./Mucuna
5		Wet 2011–2012	12/12/11	639	4	
5		Dry 2012	30/05/12	65	4	

[a] Total rainfall from 1 week prior to planting to one week prior to harvest.
[b] Treatment at Loes only.

mucuna, (2) weeding regimes: hand-weeded 1, 2 and 3 times and (3) maize varieties (local white vs. introduced Harare 52). The first-phase trial was sown on January 16, 2007 in a split–split plot design with mucuna as the main plot factor, weeding frequency as the sub-plot factor, and variety as the sub–sub-plot factor with three replications. Individual plots were 7 m × 9 m. Maize was sown first with 75 cm between rows and 25 cm within rows (5.3 plants m^2), while mucuna was planted one month later at 75 cm × 75 cm spacing between the maize rows. All plots were weeded at the time of mucuna sowing (1 month after maize planted) and then again at monthly intervals according to treatment. Plots were harvested on 25 April 2007. The two outside maize rows from each plot were discarded and excluded from the analysis of yield. However the dry weights of both weed component and mucuna above-ground vegetative growth were obtained from the entire plot. The weights were all as air-dried in this and subsequent trials. Before dry weights were taken, samples were dried of the cob for at least 3 sunny days, and again as threshed grain for at least 3 days. Occasional measurements of grain showed this reduced grain moisture below 14%.

The second phase of the maize-mucuna trial was sown on June 4, 2007. Mucuna was then planted six weeks later into one half of the plots which had been planted with mucuna in the previous phase. Only one variety of maize was planted. So the second trial was a split-plot design with the cropping combinations as the main plot factor (Table 1): Level (1) mucuna/maize grown together two times in succession; (2) mucuna/maize followed by maize alone; and (3) maize grown as a monoculture two times in succession. The frequency of weeding was in sub-plots – implemented as in the initial trial. The second trial was analyzed with GenStat using the three different crop combinations (over two seasons), three weeding treatments and three replicates for a total of 27 plots but allowing for the differences in plot size. This trial was harvested on 23 October 2007 and maize yield determined as previously described, but unfortunately no measurements of weed or mucuna were recorded.

2.3. Trial 3: Corluli 2007–2008

A further trial (#3) to assess the use of mucuna as a weed suppressant was implemented at Corluli (8°93′ S, 125°17′ E; 140 m asl), Bobonaro District in the west of the country in Usifluvent soil (map unit Atcdp in Garcia and Cardoso, 1978) with pH 6.0 (Howeler, 1996), and it evaluated the factors – time of sowing of mucuna in relation to maize and the frequency of weeding on the impact of weed density and maize yield. Regarding the treatment sowing time (Table 1), there were three sowing times for the mucuna intercrop, (1) concurrent with maize, (2) two weeks after sowing maize and (3) four weeks after sowing maize. For weeding frequency, weeding was done either once or twice during the maize crop. The trial was in a completely randomized block design with three replications. Plot size was 5 m × 5 m. Maize in the trial was sown on 23 November 2007 with 40 cm between rows with 40 cm between plants within rows. The maize variety was 'Lokal Kakatua' sourced from Maliana, Bobonaro. Mucuna was sown at 1 m × 1 m distance between the maize rows. Plots were harvested on 28 March 2008. The entire plot was harvested. Above ground weed matter was also harvested from a 4 m^2 area in each plot at maize harvest time. Weed weights were recorded.

2.4. Trial 4 at Betano in the wet seasons of 2008–2009, 2009–2010, 2010–2011 and 2011–2012, and the 2011 and 2012 dry seasons

A long-term experiment (Trial 4) at Betano research station (same as 2.2 – Trial 2) was designed to test the effect of the association of mucuna with maize from the wet season 2008 to 2009 to the dry season in 2012 (Table 1). The trials were laid out in a randomized complete block design in three replicates with 40 m × 20 m plots. Five treatments, as described in Table 1, were applied to compare mechanical ploughing as opposed to the farmers' practice of no tillage, with or without the herbicide

Table 2
Trial 1: Maize yield (t ha^{-1}) grown with different species and sowing dates of legume inter-crop at Hera in 2007.

Species	Legume sowing time			Species mean	Sole maize control
	Concurrent with maize	3 weeks after maize	5 weeks after maize		
Velvet bean	0.44	2.24	1.76	1.48	
Sword bean	1.54	2.12	1.68	1.79	
Jack bean	1.48	1.95	1.56	1.66	1.28
Mean of sowing date	1.15	2.10	1.67		
LSD (P = 0.05) main effect = 1.04 and interaction = 1.81					

glyphosate and mucuna as weed management practices. In all cases, sowing was done by placing seeds in holes made with a planting stick (standard farmer practice).

At sowing time weeds and, if need be, residual mucuna were slashed manually (as a tractor would have crushed the mucuna pods) when not sprayed with glyphosate. Prior to sowing, the soil was tilled with a tractor or not, depending on the treatment. Maize was sown with two seeds per hill at a planting distance of 75 cm × 50 cm (2.6 plants m^2). Mucuna was planted approximately a month later with a 1 plant m^2 density (one seed per hill). The plots without mucuna were weeded twice, as farmers commonly do. The weight of wet and dry weed or mucuna biomass was measured through 5 samples (quadrats of 1 m^2) prior to sowing and prior to harvest. At harvest, the number of maize plants were counted as well as the number of cobs per plot. The production per plot was weighed, prior to and after drying, as well as the weight of 100 seeds.

As no spatial effects were detected, the results were analyzed in GenStat Discovery 3 using ANOVAs (Unbalanced ANOVA for the factors analysis and ANOVA One-Way in Complete Randomized Block for the overall cropping system treatment).

2.5. *Trial 5 at Loes in the wet seasons of 2010–2011 and 2011–2012, and the 2011 and 2012 dry seasons*

The long-term trial (Trial 5) at Loes Research Station in the North East of the country (8°44′ S, 125°8′ E; 20 m asl) which has Tropofluvent soil (map unit Ap in Garcia and Cardoso, 1978) with pH 7.2 (Howeler et al., 2003), was similar in design to the long-term Betano trial – except one treatment was added: Hand sowing without mucuna (Table 1). Thus, the Loes Trial was a factorial combination of three land preparation methods with and without mucuna as an inter-crop. The three methods of land preparation were, (1) mechanical tillage, (2) weeding by hand, and (3) application of glyphosate with no soil tillage. The inclusion of all combinations of all factors allowed for the interaction effect to be measured for each of the treatment structures. Sowing dates are given in Table 1. Plots of 20 m × 12 m were laid out in randomized complete block design with four replicates. One of the replicates was affected by flooding, however; and only the remaining three were used for analysis. Maize sowing was at 75 cm × 25 cm (5.3 plants m^2). Weeding and harvest were done as at Betano (Trial 4). For the Loes factorial combination trial, a two-way ANOVA was used to investigate the method of land preparation, planting of mucuna, and the interaction of the two factors.

3. Results

3.1. *Trial 1 at UNTL in 2007*

In Trial 1, comparing legume inter-crop species and the time of sowing of the legumes at Hera, mucuna grew vigorously and reduced maize grain yield when the maize and mucuna were sown simultaneously (Table 2). Mucuna in these plots was observed to grow over the maize thereby reducing light penetration, and was competing with maize for water and nutrients. By contrast, planting any of the three legume crops improved maize yield only at P = 0.06 when planted three weeks after maize. There was a reduction in benefit by planting the cover crops after 5 weeks. Sword bean has a very toxic seed coat that was unacceptable to those testing it. Jack bean had an upright growing habit, limiting its use as a smother crop. Mucuna was observed as the most vigorous and smothering legume intercrop.

3.2. *Trial 2 at Betano in 2007*

In the first season (2007 wet season) of Trial 2 at Betano, comparing maize sole cropping with intercropping mucuna, weeding frequency and maize cultivars, mucuna had a major impact on weed load – irrespective of the number of times the plots were weeded (Table 3). The vigorous growth of mucuna also slightly reduced the yield of maize; however, this was not statistically significant. The maize varieties were affected equally by mucuna and the frequency of hand weeding. Overall the introduced variety Harare 5 (1.2 t ha^{-1}) yielded significantly higher than the local maize (0.87 t ha^{-1}).

In the following 2007 dry season at Betano, the average yield of maize cobs from plots in which mucuna was planted into twice in succession was higher (2.5 t ha^{-1} vs. 1.7) than where there was no mucuna planted only at P = 0.07 (Table 4). As a result of differences in shelling percentage, an analysis of maize actual seed yield (rather than cob weight) showed that maize yields with two mucuna plantings were significantly (P = 0.05) higher than those with no mucuna. Although data were not collected on the biomass of mucuna and weeds in the second trial, it was observed that mucuna growth was much less in the second dry-season trial compared with the initial wet-season planting in January. Also (as in the previous season trial) weed density was lower in plots which had been weeded at least twice.

3.3. *Trial 3 at Corluli in the wet season 2007–2008*

In Trial 3 (comparison of maize sole cropping with intercropping mucuna, and weeding frequency) at Corluli in the wet season 2007–2008, an initial analysis of the data showed significant row (F Prob. 0.02) and column (F Prob. 0.004) effects at the site. Using REML analysis, no treatment effects on the variates weed weight and the 'abundance' score for mucuna reached significance. The only significant factor (*Chi-sq prob.* <0.001) in the trial was the effect of the timing of mucuna planting on maize yield. Concurrent sowing of maize and mucuna gave an average maize yield of 1.5 t ha^{-1}, whereas delaying the sowing of mucuna by 2 weeks and 4 weeks resulted in greater maize yields of 4.6 and 3.5 t ha^{-1} ($LSD_{P=0.05}$ = 2.1), respectively. Clearly delaying the sowing date of mucuna to after maize planting was preferable than concurrent sowing.

3.4. *Trial 4 at Betano from 2008 to 2012*

Data collection from the long-term trial at Betano (Trial 4) in 2008 to 2009 was prevented by the growth of the mucuna over the

Table 3
Trial 2: impact of mucuna and weeding frequency on maize yield (whole cobs), mucuna dry weight and weed burden – all in t ha^{-1} – at Betano in the wet season 2007.

Weeding frequency	Maize-mucuna together			Maize monoculture	
	Maize yield	Mucuna dry weight	Weed dry weight	Maize yield	Weed dry weight
1	1.06	7.3	2.78	1.02	6.77
2	0.72	12.0	0	1.07	7.55
3	0.82	12.8	0	1.40	7.73
Mean	0.86	10.7	0.93	1.16	7.35
LSD (P = 0.05)	0.51	3.42	3.17	0.51	3.17

Table 4
Trial 2: effect of cropping system (maize after maize; maize after mucuna/maize; and maize with mucuna after maize/mucuna) on maize cob and grain yield (t ha^{-1}) at Betano in the 2007 dry season.

Weeding frequency	Maize after maize (no mucuna)	One mucuna planting	Two mucuna plantings	Mean of weeding frequencies
1	1.93	1.73	2.07	1.91
2	1.43	2.1	2.9	2.14
3	1.63	2.47	2.5	2.2
Cropping system mean for entire cob yield	1.67	2.1	2.49	
LSD (P = 0.05)	1.2			
Cropping system mean for grain yield	0.98	1.29	1.50	
LSD (P = 0.05)	0.46			

maize which was planted late due to the lack of early rain. However, the long-term implementation of maize and mucuna successions was maintained overall as well as the tillage regimes.

In the 2009–2010 wet season in the long-term trial at Betano – Trial 4, plant density at harvest and production were low (Table 5). With an ANOVA using 'Tillage', 'Glyphosate' and 'Mucuna' as unbalanced factors, 'Mucuna' (P = 0.043, LSD = 0.20) was the only factor with a significant effect on yield: Yields were 0.5 t ha^{-1} with mucuna and 0.26 t ha^{-1} without mucuna, i.e. +83% yield advantage. The most important result of the trial was the total absence of weeds in the plots cultivated with mucuna which developed into a 9 t ha^{-1} broad-leaf cover, the lower layers of which decayed into mulch, and smothered all weed development. By contrast in the plots without mucuna, where the manual control of weeds was supplemented by mechanical tillage and chemical control, a 5 t ha^{-1} gramineous weed cover had developed within the maize crop.

In the following Betano wet season 2010–2011 trial, maize sown into mucuna mulch produced significantly higher yields (77% overall yield advantage) than maize plots that had not been planted with mucuna (Table 5). All three land preparation methods produced similar results in maize yield when paired with mucuna. These higher yields came from significantly larger cobs produced in the plots with mucuna. As in the 2009–2010 Betano trial, at harvest weeds were absent from plots cultivated with mucuna. Production of mucuna mulch followed the previous year's trend with mechanical tillage producing the highest biomass followed by glyphosate and hand weeding.

In the dry season 2011 at Betano there were similar results with the mucuna treatments resulting in significantly higher yields (233% overall yield advantage) compared to the non-mucuna treated plots (Table 5). As in the previous season, greater maize cob weights in plots with mucuna contributed to the higher yields, as plant density and the number of cobs per plant did not differ significantly. In contrast to the wet season trials, there was a significant difference among the three land preparation methods when paired with mucuna. Mechanical tillage with a tractor produced the best results, followed by application of glyphosate and hand preparation. While mucuna did not entirely prevent weed growth as in the earlier wet season trials, it did result in a significant reduction in the weed burden compared to non-mucuna plots. In the dry season trial there was a very low amount of mucuna growth. This was a result of little seed produced during the wet season, and poor germination of the seed planted after the maize crop was established.

In the 2011–2012 Betano wet season trial, plots planted with mucuna produced double the yield of plots that were not intercropped (Table 5). As with previous seasons, larger cob size accounted for the increased yields in the plots planted with mucuna. The three land preparation methods were significantly different from each other, with mechanical tillage producing the best yields followed by glyphosate and hand preparation, as in the previous 2011 dry season. Weed biomass was higher in the mucuna plots than in some previous trials, but the overall benefits of planting mucuna were still clear.

In the Betano 2012 dry season, maize yield was again significantly higher in plots planted with mucuna with an average yield advantage of 169% over plots without mucuna (Table 5 and Fig. 1). Both cob and seed size accounted for the increased yield in the plots planted with mucuna. There was no statistically significant difference between land preparation methods.

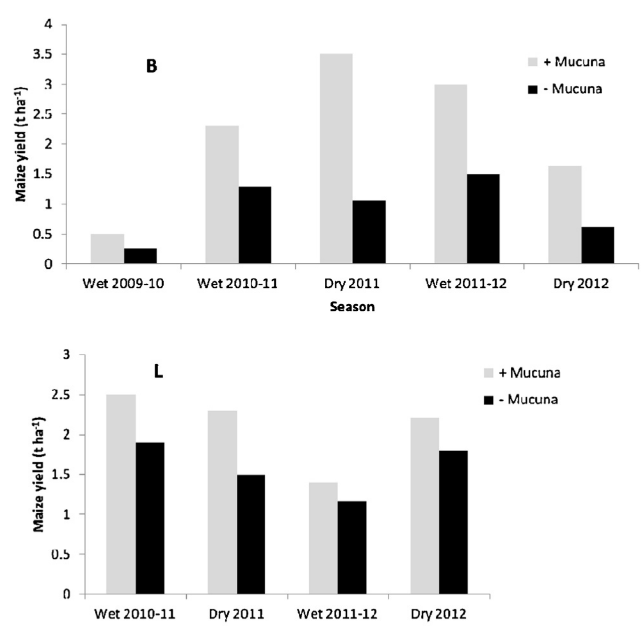

Fig. 1. Average maize yield (t ha^{-1}) with and without mucuna over rotational seasons at Betano (Trial 4) (B) and Loes (Trial 5) (L). In every season at Betano the yield advantage with mucuna was significant at P < 0.05, whereas at Loes it only reached this level of significance in the 2011 dry season.

Table 5
Maize-mucuna (Muc) results from long-term trials in Trial 4 at Betano in the wet seasons of 2009–2010, 2010–2011, and 2011–2012, and the 2011 and 2012 dry seasons.

Treatment	Dry biomass at harvest ($t\,ha^{-1}$)		Maize yield ($t\,ha^{-1}$)	Plant density at harvest (plant m^2)	No. cobs/plant	Cob weight (g) (seeds only)	Seed weight (g 100 seeds^{-1})
	Weeds	Muc					
Wet season 2009–2010							
Mech. tillage	4.8	0	0.3	0.4	1.1	83	29.3
Glyphosate	5.1	0	0.3	0.5	1.1	102	27.3
Tillage + Muc	0	9.5	0.4	0.7	1.1	84	27.3
Glyph. + Muc	0	9.3	0.6	1.5	1	71	26.0
Hand weed + Muc	0	8.2	0.5	0.8	1.1	73	27.0
LSD (P < 0.0)	3.3		ns	0.6	ns	ns	3.6
% CV	24		43	40	3	57	7
Wet season 2010–2011							
Mech. Tillage	4.3	0	1.3	1.7	1.1	69	30.3
Glyphosate	4.7	0	1.3	1.9	1.1	62	29.7
Tillage + Muc	0	11.2	2.5	2.0	1.3	100	28.7
Glyph. + Muc	0	10.4	2.2	1.7	1.1	111	32.3
Hand weed + Muc	0	8.6	2.1	1.8	1.1	105	30.3
LSD (P < 0.05)	1.6	1.9	0.8	ns	ns	26.3	ns
% CV	49	18	24	17	21	16	5
Dry season 2011							
Mech. Tillage	0.4	0	1.1	2.2	1.5	35	31.4
Glyphosate	0.4	0	1.0	2.0	1.5	32	30.3
Tillage + Muc	0.3	0.4	4.6	2.1	2.0	106	38.6
Glyph. + Muc	0.3	0	3.6	2.0	1.8	100	32.6
Hand weed + Muc	0.3	0.4	2.3	2.0	1.8	63	33.4
LSD (P < 0.05)	0.08	0.18	0.85	ns	ns	20.4	ns
% CV	15	58	18	87.9	19	16	10
Wet season 2011–2012							
Mech. Tillage	0.1	0.0	1.2	3.1	1.2	33	28.7
Glyphosate	0.2	0.0	1.7	4.6	1.3	30	29.0
Tillage + Muc	0.3	13.2	3.4	5.5	1.0	52	30.0
Glyph. + Muc	0.0	9.7	2.9	4.7	1.2	50	29.0
Hand weed + Muc	0.1	7.0	2.8	5.4	1.2	46	29.3
LSD (P < 0.05)	ns	0.3	0.24	1.04	ns	9.1	ns
% CV	129	27	5	12	5	12	4
Dry season 2012							
Mech. Tillage	0.8	0.0	0.6	2.8	1.0	21	29
Glyphosate	1.1	0.0	0.6	3.0	1.0	19	29
Tillage + Muc	0.0	1.0	1.7	3.2	1.1	48	31
Glyph. + Muc	0.0	1.0	1.6	3.0	1.2	49	30
Hand weed + Muc	0.0	1.1	1.6	2.5	1.1	59	30
LSD (P < 0.05)	0.57	0.6	0.21	ns	ns	17.9	0.5
% CV	81	47	9	15	17	24	1

ns: Non-significant at P = 0.05.

Over the seasons at Betano (2009–2012), the percentage maize yield advantage of cropping with mucuna over cropping without mucuna was significant every season and averaged 132%, raising monoculture maize yield from an average of 0.94 $t\,ha^{-1}$ to a mean of 2.19 $t\,ha^{-1}$ with mucuna. The percentage yield advantage in maize of mucuna inter-cropping tended to be greater in the dry than the wet seasons (Fig. 1).

3.5. Trial 5 at Loes from 2010 to 2012

Turning to the Loes long-term experiment (Trial 5), in the wet season 2010–2011 the planting of mucuna had a significant effect on the weed burden (Table 6). The weed biomass was reduced from an average of 4.4 $t\,ha^{-1}$ in non-mucuna plots to an average of 0.5 $t\,ha^{-1}$ with the mucuna treatments. In plots where mucuna was planted, an average of 7 $t\,ha^{-1}$ of mucuna mulch was produced. However the effect of sowing mucuna on maize yield was non-significant. This was probably due to sampling – in Loes 5 m × 5 m samples were taken to derive maize yield, whereas at Betano yield data were from whole plots. Land preparation method did not significantly affect maize yields or biomass of either mucuna or weeds. No interaction between land preparation method and planting of mucuna was found (Table 6).

In the following dry season in 2011 at Loes, there was a significant effect of mucuna on maize yields with mucuna plots producing a mean yield of 2.3 $t\,ha^{-1}$ compared to 1.5 $t\,ha^{-1}$ without mucuna (a 53% yield advantage) (Table 6 and Fig. 1). In this dry season trial mucuna did not have a significant effect on weed biomass. An average of 3.7 $t\,ha^{-1}$ of mucuna mulch was produced. As in the previous planting cycle, no interaction was found between the two factors, but land preparation method had a significant effect on maize yields and mucuna just achieved significance (F prob. = 0.05) for maize yield. Low plant densities in the glyphosate and mucuna treated plots resulted in low yields which reduced the overall effect of mucuna.

In the Loes 2011–2012 wet season trial, no significant difference was found between the treatments for maize yield or yield components (Table 6). However, there was a significant reduction of the weed burden with mucuna.

In the 2012 dry season trial, the yield advantage of mucuna was non-significant (Table 6). The weed burden was again reduced in plots planted with mucuna, but this did not have a significant effect on maize yields. As in the previous season, no interaction was found between land preparation method and mucuna.

Over the duration of Trial 5 at Loes, as at Betano, plots planted with mucuna historically produced higher yields than

Table 6
Maize-mucuna (Muc) results in Trial 5 at Loes in the wet seasons of 2010–2011 and 2011–2012, and the 2011 and 2012 dry seasons.

Treatment	Dry biomass at harvest (t ha^{-1})		Maize yield (t ha^{-1})	Plant density at harvest (plant m^2)	No cobs (plant^{-1})	Cob weight (g)	Seed weight (g 100 seeds^{-1})
	Weeds	Muc					
Wet season 2010–2011							
Mech. Tillage	4.4	0.0	2.2	2.1	1.2	161	34.3
Glyphosate	5.3	0.0	1.7	2.2	0.9	154	35.7
Hand weeding	3.4	0.0	1.8	1.8	1.3	165	34.0
Tillage + Muc	0.9	8.9	2.8	2.0	1.4	171	35.7
Glyph. + Muc	0.0	7.9	2.2	2.2	1.4	155	35.0
Hand weed + Muc	0.7	4.4	2.5	2.2	1.4	155	34.3
LSD (P < 0.05)	3.0	3.8	ns	ns	ns	ns	ns
% CV	68	59	30	19	27	10	5
F prob. of factor (number of modalities)							
Factor 1: Land prep. (3)	ns	ns	ns				
Factor 2:Muc (2)	***	***	ns				
Interaction (6)	ns	ns	ns				
Dry season 2011							
Mech. Tillage	2.8	0	1.7	2.9			29.0
Glyphosate	3.7	0	1.4	2.7			25.3
Hand weeding	3.1	0	1.3	2.4			25.3
Tillage + Muc	2.5	3.7	3.3	2.8			29.3
Hand weeding + Muc	3.1	4.6	2.8	3.0			28.0
Glyph. + Muc	2.5	2.8	0.9	1.8			24.7
LSD (P < 0.05)	ns	0.13	1.5	ns			2.1
% CV	34	38	43	21			4
Factor 1: Land prep. (3)	ns	ns	*				
Factor 2: Muc (2)	ns	***	*				
Interaction (6)	ns	ns	ns				
Wet season 2011–12							
Mech. Tillage	0.2	0.0	1.2	1.4	1.2	69	29
Glyphosate	0.3	0.0	1.3	1.4	1.0	78	29
Hand weeding	0.4	0.0	1.0	1.1	1.3	72	28
Tillage + Muc	0.0	3.3	0.9	1.3	1.1	64	28
Glyph. + Muc	0.0	3.0	1.9	1.3	1.6	101	29
Hand weed + Muc	0.1	4.1	1.4	1.3	1.2	88	29
LSD (P < 0.05)	0.14	0.8	ns	ns	ns	ns	ns
% CV	60	31	41	37	22	22	3
Factor 1: Land prep. (3)	ns	ns	ns				
Factor 2: Muc (2)	***	***	ns				
Interaction (6)	ns	ns	ns				
Dry season 2012							
Mech. Tillage	3.2	0.0	2.1	2.1	1.1	98	29
Glyphosate	4.7	0.0	2.0	1.6	1.4	88	27
Hand weeding	2.9	0.0	1.3	1.3	1.2	89	28
Tillage + Muc	0.0	4.5	2.2	2.1	1.2	91	29
Glyph. + Muc	0.0	4.8	2.3	1.9	1.3	100	29
Hand weed + Muc	0.0	3.3	2.1	12	1.9	111	29
LSD (P < 0.05)	1.3	1.7	ns	ns	ns	ns	ns
% CV	41	44	27	36	49	24	5
Factor 1: Land prep. (3)	ns	ns	ns				
Factor 2: Muc (2)	ns	*	ns				
Interaction (6)	ns	ns	ns				

ns: Non-significant at P = 0.05.
* F prob.: < 0.05.
*** F prob.: < 0.001.

those without but this difference was only significant at P < 0.05 in the dry season of 2011 (Fig. 1).

4. Discussion

Within the shifting system of cultivation in Timor-Leste the duration of cropping at any one site – usually 2–5 years – is dictated by weed growth and soil fertility, and an extended period of restorative bush fallow then follows. There is very little weed burden in the first year after clearing a forest area and crops are successfully grown with little weeding (da Costa et al., 2013). As the cleared land is planted in succeeding years, the weed burden increases until it is decided to leave that plot for a new area because of the substantial reductions in crop yield. In maize fields in Timor-Leste the predominant weeds are in descending order of importance: *Cyperus brevifolius* Rottb. most prevalent in Liquica; *I. cylindrica* particularly in Manufai; *Melinis repens* (Willd.) Zizka; *Stachytarpheta jamaicensis* (L.) Vahl; *Chromolaena odorata* (L.) King and Robinson of increasing importance (SoL, 2007, 2008); and on-station at Loes *C. rotundus* L. is an additional problem. The long-term trials at Betano and Loes confirmed that mucuna intercropping significantly reduced the weed burden on maize. The effect was often sufficient to completely eliminate weeds at harvest time. Elsewhere in the Tropics mucuna is known as a green manure for its smothering ability particularly of spear grass (*I. cylindrica*), an important weed in Timor-Leste. Because of its weed suppression ability, mucuna also significantly reduces the amount of labour required for weeding. As weeds represent a limiting factor for a Timorese farmer's ability to produce more food, mucuna merits further study with growers and may become an important method of weed management in appropriate parts of Timor-Leste.

The other key aspect of legume fallowing – in our case with mucuna – is its restorative effect on soil fertility as evidenced by maize yields. In Africa and parts of Central America mucuna is widely used in fallowing as a green manure to improve soil fertility through nitrogen fixation and leaf litter (Buckles and Triomphe, 1999; Douthwaite et al., 2002; Fischler and Wortmann, 1999; Tarawali et al., 1999). Timorese farmers are reluctant to use inorganic fertilizer to maintain fertility. At Betano over five rotational cycles the percentage maize yield advantage of intercropping with mucuna v. cropping without mucuna was 132%, lifting maize yield from a mean of 0.94 t ha^{-1} from successive mono-cropped maize to a mean of 2.19 t ha^{-1} with mucuna (Fig. 1). Such effects were recorded after only one mucuna cycle and the benefits clearly accrue rapidly. In the trials at Loes, a similar positive trend could be seen but the effect was only significant at $P < 0.05$ in one season out of four. The effect of mucuna on soil nutrient supply through its nodulation, N fixation and subsequent uptake by maize has been extensively reported (Sanginga et al., 1996; Ibewiro et al., 2000; Okito et al., 2004; Fofana et al., 2005; Kaizzi et al., 2004, 2006; Shoko et al., 2011). Effects are expected to be particularly strong on soils low in nitrogen. A meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa (Sileshi et al., 2008) indicated that the positive benefits of legumes on maize yield was from three main factors: N input from biological nitrogen fixation, retrieval of nutrients from below the rooting zone of maize, and finally a reduction of nutrient losses from leaching, run-off and erosion and improved soil water conditions. We did not measure nitrogen fixation by mucuna, but observed extensive nodulation in all trials when roots were recovered. Maize yields are low in Timor-Leste averaging 1.4 t ha^{-1} in comparison with mean productivity in SE Asia of 3.9 t ha^{-1} (FAO, 2013). The use of mucuna combined with the newly released open-pollinated maize varieties (Williams et al., 2012) should assist the country to move towards food security.

The management – especially of sowing time – of intercropped mucuna is critical. If sown too early, mucuna competes with the maize and can significantly reduce its yield. If sown too late, the mucuna grows with insufficient vigour to reduce the weed burden. The ideal timing appears to be approximately 3–4 weeks after planting maize. However, local and annual variations in rainfall patterns need to be taken into account. Vigorous and early growth of the mucuna may compete with the main maize crop in some environments, particularly if water is limiting. This was the case in the long-term trial at Betano (Trial 4) in 2008–2009 where the mucuna overgrew over the maize which was planted late due to the lack of early rain. Looking ahead at the anticipated change in climate, such droughts are anticipated to increase in frequency (Molyneux et al., 2012). The dense, leafy ground cover of mucuna improves soil characteristics and helps retain soil moisture, but its evapotranspiration could also be higher than from a bare or grassy ground, resulting in less overall moisture available in the soil for the main crop. The effects of drought on the system are not yet clear, but it is promising that the percentage yield advantage of maize intercropped with mucuna compared to sole-cropped maize tended to be greater in the dry than the wet seasons at Betano where the rotation trial ran for the longest duration.

The long-term trials (Trials 4 and 5) were also designed to test the belief common among farmers in Timor-Leste that using tractors to till the soil is the best way to prepare the land. At Betano in Trial 4 mechanical tillage with a tractor produced the best results, followed by application of glyphosate and hand preparation. This supports the idea that tractor ploughing is the best method of land preparation on level land in large plots.

Douthwaite's (2002) analysis from West Africa concluded that separate trials are needed to gather biophysical data, where researchers need to keep a high degree of control, as opposed to adoptability trials where farmers must be able to manage the technology as they wish. Biophysical trials in Timor-Leste are reported herein and looking ahead it is now important to move into participatory adoptability research on mucuna with farmers in suitable long-growing season environments. In the process it will important to highlight the immediate gains to growers, to optimize the multiple benefits of mucuna cropping, and to design promotional strategies, and appropriate policies to bring Timorese farmers to re-adopt this agronomic system in appropriate parts of the country. There will also be an opportunity to further evaluate whether the technology needs to be adapted for the different agro-ecosystems across the country.

5. Conclusions

- In the context of maize as the staple crop in Timor-Leste, comparing continuous maize cropping with maize relay-sown with mucuna, intercropping significantly reduced the weed burden on maize. The effect was often sufficient to completely eliminate weeds at harvest time.
- In the South of Timor-Leste over five rotational cycles the percentage maize yield advantage of cropping with v. cropping without mucuna was significant at 132%, lifting maize yield from a mean of 0.94 t ha^{-1} from successive monocrop maize to a mean of 2.19 t ha^{-1} with mucuna.
- Management of the mucuna relay sowing time into maize is particularly critical.
- Participatory research with farmers is now required to bring Timorese farmers to re-adopt this agronomic system in appropriate parts of the country.

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