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ON-FARM EXPERIMENTS WITH MAIZE-MUCUNA SYSTEMS IN THE LOS TUXTLAS REGION OF VERACRUZ, MEXICO. I. MUCUNA BIOMASS AND MAIZE GRAIN YIELD

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SUMMARY

Maize (*Zea mays*)-mucuna (*Mucuna pruriens*) systems have been promoted to the smallholder farmers of the Los Tuxtlas region of southeastern Veracruz, Mexico. To determine on-farm performance, an agronomic assessment was conducted in 1995–97 replicating farmer conditions in four fields. Treatments were first- and second-season maize with first-season mucuna (system Zm-Mp/Zm), first-season maize with first- and second-season mucuna (system Zm-Mp/Mp), second-season maize following first-season mucuna (system Mp/Zm), and first- and second-season maize, no mucuna control. Data on mucuna biomass amount and quality as well as maize yield, yield components, and nutrient status were collected. Highest mucuna biomass was obtained in system Mp/Zm (leaf-stem-mulch biomass in 1996/97, 7.34 t ha^{-1}, 147 kg ha^{-1} N), followed by systems Zm-Mp/Mp (5.06 t ha^{-1}, 101 kg N ha^{-1}) and Zm-Mp/Zm (2.75 t ha^{-1}, 50 kg N ha^{-1}). Second-season maize yield was increased over that of the control by 45–58 % (0.15–0.23 t ha^{-1}) in system Zm-Mp/Zm and by 118 % (0.60 t ha^{-1}) in system Mp/Zm. Mucuna did not increase first-season maize yield. Climatic constraints make second-season maize production risky and yield increases due to mucuna are low in absolute terms, perhaps not offsetting labour costs (systems Zm-Mp/Zm and Mp/Zm) or loss of first-season maize (Mp/Zm).

INTRODUCTION

In the last decade, interest in green manure/cover crops has greatly increased. This is due to their potential to improve sustainability and productivity of tropical smallholder farming in the face of deteriorating soil fertility and limited or no access to external inputs. Great interest has been focused especially on *Mucuna pruriens*, described as 'without doubt one of the most popular green manure crops currently grown for the tropics' (Buckles, 1995). A growing body of experimental evidence has documented mucuna's capacity to establish ground cover rapidly, produce a large above-ground biomass, and accumulate nutrients, with consequent beneficial impacts on main crop yields in various environments (Carsky *et al*., 1998). In the overwhelming majority of mucuna studies and cases of farmer utilization, the main crop has been maize (*Zea mays*).

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In the Los Tuxtlas region of southeastern Veracruz, Mexico, mucuna has been promoted to the region's smallholders. This region is inhabited both by mestizos and by indigenous Nahua and Popoluca people, most of whom cultivate maize for subsistence and for sale. Several minor crops have varying importance (including *Phaseolus vulgaris*, *Arachis hypogaea*, *Sechium edule*, *Manihot esculenta*, and *Coffea* spp.).

Environmental conditions in most of the region allow two maize seasons within one cropping cycle. The first cropping season focuses on June-planted, rainy-season *maíz temporal* (hereafter referred to as 'first-season maize'), typically planted on 1–3 ha by a household. In the second (minor) cropping season, *maíz tapachole* (hereafter 'second-season maize') is typically relay-intercropped in the mature first-season maize in November; areas planted to second-season maize are normally small, no more than 0.3–0.5 ha. Yields are low, and have been estimated to be 1.2 t ha^{-1} for first-season maize and 0.5 t ha^{-1} for second-season maize (Buckles and Erenstein, 1996). Low soil fertility and pests constrain yields in both seasons, while additional second-season constraints include low and erratic rainfall and high winds (Buckles and Erenstein, 1996).

Maize farming largely continues to employ traditional practices including residue burning prior to first-season maize planting, use of traditional maize varieties and wide row spacing, reliance on labour inputs, and the utilization of simple tools such as the machete and dibble stick. Fertilizer use is currently very limited, while herbicide use is the norm. In recent decades, fallow periods have declined or been discontinued totally, while the traditional cultivation of diverse species has all but ceased (Paré *et al*., 1994; Buckles and Erenstein, 1996).

Although mucuna had been spontaneously adopted in a few communities of this region decades ago, its use remained limited (Buckles and Perales, 1995). In 1991, a Mexican non-governmental organization (NGO), Proyecto Sierra de Santa Marta, together with the International Maize and Wheat Improvement Center (CIMMYT), initiated work on mucuna for soil-fertility enhancement. During the first year, the work involved farmer-managed, on-farm testing including several maize-mucuna systems; the NGO's promotion efforts involving farmer extensionists and project technicians started the following year. It was estimated that in 1992–93, 2250 people in over 45 villages were reached through the promotion efforts; of these, 1164 accepted mucuna seed given by the NGO (Buckles and Perales, 1995). As a result, farmers in some of the region's villages started relay-intercropping mucuna in first-season maize. While no studies had been conducted to assess the rate of farmer adoption of mucuna, extensive interaction between the senior author and farmer extensionists and farmers prior to initiating the current experiments (Eilittä, 1998) lent support to a conclusion that the promotion efforts had resulted in disappointing adoption.

Key gaps in the general understanding of mucuna performance persist. Carsky *et al*. (1998) have suggested the need for research on a number of issues, including *ex post* studies on the biophysical and socio-economic conditions under which mucuna systems have been adopted. Information is still lacking on mucuna's growth and impact on main-crop yield in the environmental and management conditions of tropical smallholders, where poor soil fertility, suboptimal management, and intercropping, among other factors, may affect the system's performance. Such gaps in understanding also characterized the Los Tuxtlas region of southern Veracruz where no agronomic or in-depth adoption studies had been conducted following the promotional efforts. The aim of this study was to conduct a detailed characterization of farmer management of mucuna and quantify its performance (i.e. biomass production and impact on maize yield) in farmer conditions. In addition, the study was designed to determine if agronomic factors could explain the relatively low adoption of mucuna in the region.

To better understand on-farm performance of mucuna systems, both experimental and observational (e.g. agronomic monitoring) methods can be used. Agronomic monitoring can provide valuable information on farmer practices but, in the Los Tuxtlas environment where the research was conducted, large within-field variability makes it difficult to derive definite conclusions from this means alone (Eilittä, 1998). In addition, therefore, on-farm experimentation was carried out to assess mucuna biomass production and its impact on maize yield in three maize-mucuna systems and one no-mucuna control system. To replicate farmer conditions, characteristic, low-yielding fields were chosen for the experiments, and maize and mucuna management in the on-farm trials mimicked typical farmer practices.

MATERIALS AND METHODS

The Los Tuxtlas region is located in the southern part of Veracruz state at 18° 10'N to 18° 45'N, and 92° 42'W to 95° 27'W. Bordered by the Gulf of Mexico to the northeast, this mainly rural region encompasses an area of approximately 78 by 40 km. The region is renowned for its great geographic and species diversity. In recent decades, however, severe deforestation attributable to cattle ranching and to both endemic population growth and in-migration, has caused general deterioration of natural resources, including agricultural soils. Of volcanic origin, the area is undulating to mountainous, with altitudes ranging from 200 to approximately 1700 m asl. The average annual temperature is between 22 and 26 °C, with highest extremes in May and lowest extremes in January. The total annual rainfall varies from 1200 to over 4000 mm. Typically, the rains start in June and are heaviest between July and September; rainfall is greatly reduced between January and May. Between 1987 and 1996 the average annual rainfall in the regional town of Catemaco, located close to these experiments, was 1890 mm, with a range between 1440 and 2560 mm. The region's soils have not been studied in detail; they are variable and consist of Andisols, Alfisols, Ultisols, Vertisols and Entisols (Tasistro, 1994). In the past 40 years, soil fertility has been estimated to have decreased by 70–75 % (Tasistro, 1994 citing Uresti *et al*., 1992), and deficiencies of N and P are common.

This trial was designed to mimic farmer systems and practices in the study area. In practice, the application of this principle meant that: (i) local maize varieties were used in the trials; (ii) maize was planted in typical arrangements and densities; (iii) pest control measures were applied following the local practice, i.e. only used in extreme cases; and (iv) management was designed to be labour saving. To minimize organic matter and nutrient loss, existing farming systems were not mimicked in one

Table 1. Description of the maize-mucuna systems evaluated.

Maize-mucuna system	Cycle 1† First-season 1995	Cycle 1† Second-season 1995/96	Cycle 2 First-season 1996	Cycle 2 Second-season 1996/7	Cycle 3‡ First-season 1997
Zm-Mp/Zm	Maize/mucuna	Maize	Maize/mucuna	Maize	Maize/mucuna
Zm-Mp/Mp	Maize/mucuna	Mucuna	Maize/mucuna	Mucuna	Maize/mucuna
Mp/Zm§	—	—	Mucuna	Maize	Mucuna
Control	Maize¶	Maize	Maize	Maize	Maize

† Only second season of cycle 1 constituted a part of the experiment.
‡ Only first season of cycle 3 constituted a part of the experiment.
§ Treatment included in cycles 2 and 3 only after the originally planned treatment failed in cycle 1.
¶ In these plots, farmer-planted mucuna plants and their roots were removed with a shovel.

important aspect, namely, no burning of crop residues was carried out, even though a large proportion of the maize-mucuna farmers in the region do continue to burn their fields prior to first-season maize cultivation. This trial was managed by co-operating farmers according to the researcher's instructions (second-season 1995/96 and first-season 1997) or by the researcher (first-season 1996 and second-season 1996/97); there were no differences between management by researcher and farmers.

The trial was conducted in three fields in the community of La Candelaria and in one field in Santa Rosa Cintepec over four seasons covering three cropping cycles: second-seasons 1995/96 and 1996/97, and first-seasons 1996 and 1997. These communities were chosen for a number of reasons: they were representative of a large area of the region, interest in mucuna in these communities was relatively high, and they were easily accessible. The fields chosen were lower-than-average- to average yielding. The soil pH varied between 6.0 and 6.4. Exchangeable phosphorus (P) (Mehlich I) was low, ranging from 2.7 to 3.4 mg kg^{-1} (average 3.1 mg kg^{-1}) at 0–50 mm, and from 2.1 to 2.2 mg kg^{-1} (average 2.1 mg kg^{-1}) at 50–200 mm, while exchangeable potassium (K) ranged from 119 to 332 mg kg^{-1} (average 189 mg kg^{-1}) at 0–50 mm but often was relatively low, from 55 to 109 mg kg^{-1} (average 68 mg kg^{-1}) at 50–200 mm.

The trial design was a randomized complete blocks, with three replicates per field. Plot size was 5 m × 5 m. The maize-mucuna systems consisted of those used by farmers in the study communities (Zm-Mp/Zm and Zm-Mp/Mp) as well as one that had been spontaneously adopted previously by farmers in a few other communities in the region (Mp/Zm). System Zm-Mp/Zm consisted of first- and second-season maize with first-season mucuna (Table 1). First-season maize was planted in June; mucuna was planted 40 days later in early August into the maize. Mucuna was slashed just prior to planting the second-season maize (in late October–early November). The second-season maize was planted between the rows of mature first-season maize into the mucuna mulch. System Zm-Mp/Mp had only first-season maize with first-season-planted mucuna. Mucuna was relay-intercropped into June-planted, first-season maize at 40 days after planting (DAP) i.e. in August, and allowed to mature and senesce in the field (late December to early February). In system Mp/Zm, second-season maize followed first-season mucuna. Mucuna was sole-cropped during the first season (June to late October or early November), and slashed prior to second-season maize planting in early November. This treatment was included in the trial starting from first-season 1996 (i.e. the beginning of the second cycle of the experiment). The control treatment was first- and second-season maize without mucuna. In early November, second-season maize was planted between the rows of mature June-planted, first-season maize. This treatment represented the no-mucuna comparison. Large within-field variability prevented the inclusion of a larger number of treatments.

Four fields in which farmers had intercropped mucuna with maize for the first time in August 1995 were chosen. In early October 1995, plots were laid out in areas with a uniform field history, and mucuna plants in the no-mucuna plots (control) were removed with a shovel. In the other plots, mucuna was left growing for one more month. The plots were then weeded using a machete, with care being taken to avoid damaging the growing mucuna. The first-season maize crop was harvested but not weighed, as it did not constitute part of the trial.

Measurements were made of mucuna biomass just prior to slashing (typically in early November) in systems Zm-Mp/Zm and Mp/Zm, to estimate mucuna's maximum contribution in the system. In system Zm-Mp/Mp, it was measured at estimated maximum growth (typically in January). Due to row-induced differentiated growth of mucuna (more biomass in maize rows), two quadrats covering two maize rows (1995: in opposite corners) or one maize row (1996/97: representative site chosen) were marked out. The dimensions of the quadrats, 2×2 m (1995) or 1×1 m (1996), were noted for subsequent biomass calculations. Sole-cropped mucuna was measured from two representative 1×1-m quadrats. In all systems, only above-ground biomass including leaf, stem, and pods in 1995 and leaf, stem, pods, and mulch in 1996/97 was measured. The mulch fraction included all dead plant residues on the soil surface, excluding residues of woody plants. In both years, live weeds were separated and measured. All fresh-weight measurements were taken using hanging balances, and plot-level samples (300–500 g) of each fraction were oven-dried and the dry weights recorded. Further nutrient analysis was performed on biomass fractions in 1996. Weeds (in control plots) or mucuna and weeds (in systems Zm-Mp/Zm and Mp/Zm plots) were then immediately slashed, and left within the plots.

For second-season maize in systems Zm-Mp/Zm, Mp/Zm, and in control plots, a traditional maize variety was planted with a dibble stick at hill spacings of 1×1 m, with three seeds per hill (30 000 seeds ha^{-1}). Plots were weeded manually. In second-season 1996/97, maize ear leaves of all plants in four to five hills were cut at tasselling stage, oven dried at 60–70 °C, and analysed for N and P. In system Zm-Mp/Mp plots, no additional second-season management was performed. Second-season maize was harvested in the whole plot in system Zm-Mp/Zm and control plots (1996), or in the nine interior hills in 1997 in systems Zm-Mp/Zm and Mp/Zm, as well as in control plots. The numbers of hills, plants, and cobs were counted. Cobs were divided into healthy, partially damaged, and damaged groups, then counted, shelled, and weighed using hanging scales. Grain weight was measured and moisture determined with a Dickey John HM Grain Moisture Tester. Grain weights are reported at 15% moisture.

Prior to first-season planting, all experimental plots were slashed with a machete. In plots of systems Zm-Mp/Zm, Zm-Mp/Mp, and the control, first-season maize was planted in hills spaced 0.8 × 1 m with three seeds per hill (37 500 seeds ha^{-1}). In system Mp/Zm plots, mucuna was planted on the same date as maize at a spacing of 0.8 × 0.5 m with two seeds per hill (50 000 seeds ha^{-1}). As mentioned earlier, these planting patterns were similar to those the farmers used normally. Maize plots were weeded manually as needed, while mucuna plots (system Mp/Zm) were weeded once, at 30 DAP. At 40 DAP the maize in systems Zm-Mp/Zm and Zm-Mp/Mp, mucuna was intercropped at the maize hill spacing of 0.8 × 1.0 m but with two seeds per hill (25 000 seeds ha^{-1}). Maize was doubled over (i.e. maize stem bent below the ear) at physiological maturity and harvested following the previously described procedure.

Mucuna biomass fractions and maize ear leaves were oven dried and ground in a Wiley Mill to pass a 1-mm stainless steel screen. Weights of mucuna biomass fractions are reported on a dry matter basis. For N and P analysis, samples were digested using an aluminium block digestion procedure and the nutrients were determined by semi-automated colorimetry.

Data were analysed using mainly SAS GLM software (SAS Institute, 1989). The general form of the model was:

$$Y = \mu + \text{Field} + \text{Replication (Field)} + \text{System} + \text{Field by System} + \text{Error}.$$

Field was tested using replication (field) as the error term, and system and field-by-system interaction were tested using residual error. Pre-planned contrasts were used to compare systems. Correlations and regression analyses were also used.

RESULTS

Mucuna biomass

In all three cycles of the experiment, there were system effects on total mucuna biomass production. In the first cycle (1995/96), mucuna biomass was measured in all fields for system Zm-Mp/Zm only. For this system, leaf-stem biomass averaged 1.12 t ha^{-1} and the effect of field approached significance ($p = 0.053$). For system Zm-Mp/Mp, biomass was measured only in one field due to unusually early senescence of mucuna. Leaf-stem biomass in this field, the highest yielding of the four experimental fields, averaged 3.99 t ha^{-1}.

In the second cycle (1996/97; Table 2), combined mucuna leaf-stem-mulch biomass averaged 2.75, 5.06, and 7.34 t ha^{-1} for systems Zm-Mp/Zm, Zm-Mp/Mp, and Mp/Zm respectively. Differences among systems in this response and those of most other biomass components were clear. For system Zm-Mp/Zm, relatively low total mucuna biomass was associated with low mulch biomass, while the higher biomass production of systems Zm-Mp/Mp and Mp/Zm was associated with high mulch and stem biomass. Large variability in mulch biomass seemingly was caused by the differing amount of mulch of non-mucuna origin from previous years. Particularly noteworthy

Table 2. Mucuna biomass (t ha^{-1}) in maize-mucuna systems in 1996/97. Data are means across four fields.

Maize-mucuna system	Leaf	Stem	Mulch	Pod§	Weed	Leaf + stem + mulch
Zm-Mp/Zm†	0.46	0.50	1.79	0.02	1.24	2.75
Zm-Mp/Mp‡	0.31	0.53	4.23	1.40	1.41	5.06
Mp/Zm†	0.57	1.64	5.13	0.39	1.01	7.34
s.e.	0.047	0.051	0.458	0.098	0.144	0.468

† Mucuna biomass sampled at slashing of mucuna, typically in early November.
‡ Mucuna biomass sampled at maturity of mucuna, typically in January.
§ Included immature pods.

is the high stem weight and, therefore, low leaf : stem ratio under system Mp/Zm conditions. Field observations indicated greater leaf shedding in system Mp/Zm's sole-cropped conditions, beginning at two months after planting (presumably due to self-shading). This contributed to a thick mulch layer by the early November slashing.

Understandably, pod weight was highest in system Zm-Mp/Mp (1.40 t ha^{-1}), where mucuna was allowed to reach maturity. Under systems Zm-Mp/Zm and Mp/Zm, pods produced were typically immature and low in number. Presence of pods varied greatly with field and plot.

Though weed biomass was only slightly lower in system Mp/Zm (1.01 t ha^{-1}) than in Zm-Mp/Zm (1.24 t ha^{-1}) or Zm-Mp/Mp (1.41 t ha^{-1}), weed percentage of the total biomass was 30 and 20 % in systems Zm-Mp/Zm and Zm-Mp/Mp respectively, while it was only 12 % in system Mp/Zm. This suggests that, in system Mp/Zm, mucuna competed effectively with weeds. Large variability in weed biomass was caused mainly by within-field differences in weed pressure.

Significant field differences were found for all fractions measured. There was significant field × system interaction for pod weight only ($p = 0.001$). Interaction occurred because, in one field, pod production tended to be higher in system Mp/Zm plots (680 kg ha^{-1}, immature pods) than in system Zm-Mp/Mp plots (560 kg ha^{-1}; consisting of mature pods) while, in other fields, system Zm-Mp/Mp pod yields were greater.

Nitrogen and phosphorus were measured only during the second cycle (1996/97), and mirrored the year's biomass findings. In system Zm-Mp/Zm leaf, stem, and mulch fractions averaged 50 kg N ha^{-1}, while the N content for system Zm-Mp/Mp was approximately 100 kg ha^{-1} and for system Mp/Zm, approximately 150 kg ha^{-1} (Table 3). Nitrogen content in the weed fraction was relatively high, totalling 28, 28, and 22 kg ha^{-1} in systems Zm-Mp/Zm, Zm-Mp/Mp, and Mp/Zm respectively. Findings regarding P content largely mirrored those for N (Table 3). Differences in residue quality, expressed as N % and P % of different mucuna plant fractions, were minor except for mulch N where the average concentration for system Zm-Mp/Zm was 1.32 %, for system Zm-Mp/Mp, 1.84 %, and for system Mp/Zm, 1.90 %. The significantly higher N concentrations in the last two systems were presumably due to greater leaf shedding than in system Zm-Mp/Zm.

Table 3. Nitrogen and phosphorus content (kg ha^{-1}) of the weed and mucuna leaf + stem + mulch biomass fractions in maize-mucuna systems in 1996/97. Data are means across four fields.

Maize-mucuna system	Nitrogen		Phosphorus	
	Weed	Leaf + stem + mulch	Weed	Leaf + stem + mulch
Zm-Mp/Zm[?]	28	50	1.8	3.4
Zm-Mp/Mp[?]	28	101	1.8	5.5
Mp/Zm[?]	22	147	1.3	9.4
s.e.	2.9	10.4	0.20	0.69

[†] Mucuna biomass sampled at slashing of mucuna, typically in early November.
[‡] Mucuna biomass sampled at maturity of mucuna, typically in January.

Table 4. Mucuna biomass (t ha^{-1}) in maize-mucuna systems in 1997. Data are means across four fields.

Maize-mucuna system	Leaf + stem	Mulch	Pod[§]	Weed	Leaf + stem + mulch
Zm-Mp/Zm[†]	1.06	3.68	0.01	0.84	4.73
Mp/Zm[‡]	1.90	4.27	0.26	1.68	6.16
s.e.	0.163	0.452	0.027	0.225	0.483

[†] Mucuna biomass sampled at slashing of mucuna, typically in early November.
[‡] Mucuna biomass sampled at maturity of mucuna, typically in January.
[§] Included immature pods.

In the third cycle (1997/98), biomass fractions were measured only in early November and, therefore, only in systems Zm-Mp/Zm and Mp/Zm (Table 4). The combined leaf, stem, and mulch fraction of system Mp/Zm exceeded that of system Zm-Mp/Zm. The total mucuna biomass for system Mp/Zm was somewhat lower than the previous year, presumably because mucuna planting had been delayed due to late rains and due to delayed weeding in two of the experimental fields. Mulch biomass in system Zm-Mp/Zm was approximately double that of the previous year, presumably due to the fact that the fields had not been burned for two years. Greater weed concentrations could have contributed also. As found earlier, great variability characterized pod and weed fractions. Mulch fraction variability was less than in the previous year.

Maize yield by season

No significant system × season interaction was found for maize yield. However, because such analysis was conducted only for maize-mucuna system Zm-Mp/Zm and the control, which were common to the four seasons studied, results of the three different cycles are discussed separately, starting with second-season results.

In the second season of the first cycle (1995/96), maize yield in system Zm-Mp/Zm, (first-season maize-mucuna followed by second-season maize) was 55 % greater than in the no-mucuna system (Table 5). There was no effect of field on maize yield.

Table 5. Maize yield (t ha^{-1}) in maize-mucuna systems. Data are means across four fields.

Maize-mucuna system	Second-season 1995/96	First-season 1996	Second-season 1996/97	First-season 1997
Zm-Mp/Z†	0.41	1.00	0.74	0.94
Zm-Mp/Mp‡	¶	1.09	¶	1.00
Mp/Zm§	‖	¶	1.11	¶
Control	0.26	0.96	0.51	0.81
s.e.	0.030	0.019	0.090	0.076

† First- and second-season maize with first-season mucuna.
‡ First-season maize with first- and second-season mucuna.
§ Second-season maize following first-season mucuna.
¶ Maize not produced during this season.
‖ Treatment included in second year only.

Table 6. Maize yield components in maize-mucuna systems during second-seasons 1995/96 and 1996/97 and ear leaf N and P concentration in second-season 1996/97. Data are means across four fields.

	Second-season 1995/96			Second-season 1996/97			
Yield component	System Zm-Mp/Zm†	Control	*s.e.*	System Zm-Mp/Zm†	System Mp/Zm‡	Control	*s.e.*
Plants ha^{-1}	24 430	24 430	537	20 090	25 930	21 020	1670
Ears ha^{-1}	11 570	9 630	783	13 430	19 910	12 590	1003
Ears $plant^{-1}$	0.48	0.39	0.034	0.64	0.77	0.61	0.034
Grain cob^{-1} (g)	34	25	2.1	49	53	38	3.8
Ear-leaf N (%)	§	§		1.9	2.0	1.9	0.05
Ear-leaf P (%)	§	§		0.17	0.18	0.17	0.006

† First- and second-season maize with first-season mucuna.
‡ Second-season maize following first-season mucuna.
§ Variable measured only during second-season 1996/97.

In the second season of 1996/97 (second cycle), similarly large comparative yield increases were found in the system where August-intercropped mucuna was slashed just prior to second-season maize planting (system Zm-Mp/Zm). Across fields, yield increased by 45 % over the no-mucuna system (0.74 t ha^{-1} v. 0.51 t ha^{-1}, respectively; Table 5). As discussed earlier, the average N content of system Zm-Mp/Zm mucuna biomass at slashing was lowest at 50 kg ha^{-1}; despite this, yield increases were clear and substantial. System Mp/Zm, in which second-season maize followed first-season, sole-cropped mucuna, yielded 1.11 t ha^{-1} of maize; this represented an average of 118 % more than the no-mucuna control, but only 49 % more than maize-mucuna system Zm-Mp/Zm. As in the previous second-season cycle, there were no differences among fields in maize yield.

Such yield increases in the maize-mucuna systems were associated with increased ear grain weight, indicating more beneficial conditions during the grain-filling phase (Table 6). System Mp/Zm conditions also increased the numbers of ears ha^{-1} and of ears $plant^{-1}$, compared with system Zm-Mp/Zm (Table 6). In this second cycle,

Table 7. Annual maize productivity (t ha^{-1}) in maize-mucuna systems. Data are means across four fields.

Maize-mucuna system	Second season 1995/96 + First season 1996	Second season 1996/97 + First season 1997
Zm-Mp/Zm†	1.41	1.57
Zm-Mp/Mp‡	1.09	1.00
Mp/Zm§	¶	1.08
Control	1.22	1.31
s.e.	0.098	0.074

† First- and second-season maize with first-season mucuna.
‡ First-season maize with first- and second-season mucuna.
§ Second-season maize following first-season mucuna.
¶No System Mp/Zm treatment in second-season 1995/96.

maize ear leaf N concentration was only slightly higher in the maize-mucuna system Mp/Zm than in the no-mucuna comparison; for P, no difference was found (Table 6). In the second season of both first and second cycles, lower pest and disease incidences were also associated with mucuna systems. In the first cycle, 59 % of the cobs were partially damaged in the no-mucuna control while, in system Zm-Mp/Zm, only 49 % were damaged. In the second cycle, 84 % of the ears in the no-mucuna plots were partially damaged in comparison with 63 and 76 % in systems Zm-Mp/Zm and Mp/Zm respectively.

In contrast to the two second-season maize cycles, there were no differences in first-season maize yield among any of the maize systems studied. In the first cycle (1996), the no-mucuna control yielded 0.96 t ha^{-1} while the maize-mucuna system Zm-Mp/Zm yielded 1.00 t ha^{-1} and system Zm-Mp/Mp, with no previous second-season maize, yielded 1.09 t ha^{-1} (Table 5). The absence of response to mucuna was consistent across fields (no field by system interaction), and there were no yield differences among fields. It should be noted that biomass production in some fields may have been unusually low because mucuna senesced early during the previous second season, due to low rainfall. Similarly, in the first-season of 1997, the no-mucuna treatment yielded 0.81 t ha^{-1}, while the maize-mucuna system Zm-Mp/Zm yielded 0.94 t ha^{-1} and system Zm-Mp/Mp produced 1.00 t ha^{-1}; there was no interaction between system and field. As discussed above, total mucuna N content in system Zm-Mp/Mp in the previous year was twice that of system Zm-Mp/Zm (averaging 101 kg ha^{-1}). Despite relatively high N content, no effects were detected.

Annual maize yield

To provide an overall assessment of maize productivity over a longer timeframe, yields were combined across cycles: (i) second-season 1995/96 + first-season 1996, and (ii) second-season 1996/97 + first-season 1997 (Table 7). Though no difference was detected for the first period, for the second period (second-season 1996/97 + first-season 1997), the maize yield in system Zm-Mp/Zm exceeded maize yield in the no-mucuna control by 0.26 t ha^{-1}. Though there was no significant difference between system Zm-Mp/Mp and the control in the first annual production, in the second one, annual production of the no-mucuna control (1.31 t ha^{-1}) exceeded maize productivity in system Zm-Mp/Mp by 0.31 t ha^{-1}. In the second annual period, while maize yields were clearly increased by double-cropping, no overall positive effect in maize yield from mucuna's inclusion was found.

DISCUSSION

System Zm-Mp/Zm, used by farmers where August-intercropped mucuna is slashed prior to second-season maize planting, increased second-season maize yield by an average of 50 % despite low mucuna biomass. No clear residual effect was detected on the subsequent first-season maize yield. System Zm-Mp/Mp, the most commonly practised maize-mucuna system in the region, where mucuna is intercropped in first-season maize and allowed to mature in the field, did not increase first-season maize yield during its first two years despite relatively high mucuna biomass. Annual maize production was low in system Zm-Mp/Mp due to single cropping. The absence of a clear first-season maize yield response in both systems could have been caused by lengthy time lag prior to planting first-season maize (in system Zm-Mp/Mp, time between mucuna senescence and next maize planting is typically five to six months). This has been associated with nutrient losses through different avenues, including rapid mineralization of mucuna (Carsky *et al*., 1998; van Noordwijk *et al*., 1995), though systems with long time lags have also been reported to increase maize yield (Ile *et al*., 1996). In Los Tuxtlas, the period when mucuna residues are in the field is dry and windy, and consequent biomass losses are high. As mentioned earlier, remaining residues were left on the ground in the beginning of the season, and no burning was conducted.

The greatest mucuna biomass production and highest subsequent impacts on second-season maize production were found in the rotational system Mp/Zm, where mucuna was sole-cropped during the first season, and second-season maize planted after mucuna slashing. Several other studies have attested to mucuna's consistently good performance in sole-cropped conditions, and associated large yield increases in subsequent main crops from the rotational inclusion of mucuna in the cropping system (Carsky *et al*., 1998). It should be noted, however, that the difference in biomass production in Veracruz, between the intercropped systems (Zm-Mp/Zm and Zm-Mp/Mp) and the sole-cropped system (Mp-Zm), cannot be considered a result of intercropping alone. Mucuna grown under system Mp-Zm conditions thrived due to the long and rainy growing season, absence of light competition and high planting density. In contrast, the growing season for system Zm-Mp/Zm was short due to slashing in early November while, in system Zm-Mp/Mp, low second-season rainfall and early onset of maturity limited growth.

The positive second-season maize yield increases in systems Zm-Mp/Zm (with low mucuna biomass) and Mp/Zm (high biomass) are consistent with other reports documenting mucuna's rapid mineralization and subsequent yield impacts (Costa *et al*., 1990; van Noordwijk *et al*., 1995). Moreover, as has been reported in Atlantic Honduras (Triomphe, 1996), mucuna had a positive impact on second-season maize yield from the first cycle onwards. The low maize yield, even with previous mucuna, as well as yield component data, low ear leaf N concentration, and field observations suggest, however, generally unfavourable growing conditions. Critical values for N and P concentration at tasselling are approximately 3 % and 0.25 % respectively (Jones *et al.*, 1990), while concentrations in the current study were 1.93 % and 0.17 %. In contrast, in the Atlantic Honduras maize-mucuna system (Triomphe, 1996), maize ear leaf N concentrations were considerably higher (2.81 % and 2.41 %, in 1993 and 1994 respectively) and second-season cropping conditions were favourable. Indeed, in the Los Tuxtlas region the second-season cropping cycle is risky. Traditionally it is considered a minor maize cropping cycle due to low and erratic rainfall and frequent high winds. Though it is likely that the continued presence of mucuna as a cover crop can alleviate some of the specific constraints of the second-season maize cycle (e.g. by conserving moisture due to the mulch layer), yield increase in absolute terms may not be enough to offset the loss of first-season maize. It should be noted that despite high relative yield increases in systems Zm-Mp/Zm and Mp/Zm, these yield increases are low in absolute terms, even without considering the greater labour costs (Zm-Mp/Zm) or loss of first-season maize (Mp/Zm).

Importantly, most farmers participating in the initial on-farm experiments in the region between 1991–93 chose maize-mucuna systems that enabled first-season maize production (Buckles and Perales, 1995). As discussed by Akakpo *et al*. (2000) for southern Benin, in areas where farmers are unable to forego a season's maize production, mucuna could still have potential as a short-term fallow, which farmers could rotate on an annual basis. System Mp/Mz could be one such alternative.

Methodologically, the experiments were useful in that by replicating farmer conditions they shed additional light on the performance of the farmer-managed maize-mucuna systems in the region. Field trials were particularly suited to the study area because of very high within- and between-field variability, which made it difficult to obtain reliable data using an observational approach alone (Eilittä, 1998).

The performance and profitability of all three maize-mucuna systems evaluated could be improved greatly by increasing markets for mucuna beans (system Zm-Mp/Mp), or by finding agronomic solutions to second-season production constraints (e.g. utilization of short-season maize varieties during second season) (systems Zm-Mp/Zm and Mp/Zm), as well as by finding mucuna accessions or other green manure/cover crops that may survive over the dry season and better synchronize therefore with first-season maize. In this regard, the subsequent large-scale mucuna seed purchases by the Mexican government's Ministry of Environment and Natural Resources, as well as continued on-farm experimentation in the region, are promising. Evaluation of mucuna's potential as food and feed is needed, and could further contribute to making such systems more profitable for small-scale farmers.

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