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RESEARCH ARTICLE

Maize grain and straw yields over 14 consecutive years in burned and mulched *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* relay cropping systems

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Abstract

The cover crops *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* were introduced to African farmers to improve crop production on degraded soils, yet they appear not to be adopted at scale. In the humid forest zone of West and Central Africa, the dominant Acrisols and Nitisols are inherently poor even when not degraded through agriculture. In this zone, sole maize cropping and vegetable production systems are gaining importance, yet both suffer from nutrient deficiencies. Cover crops were often introduced along with a system change, requiring biomass retention, mainly for nutrient retention reasons. Farmers in the zone commonly use slash and burn systems due to added weed control and ease of operations on clean fields. This study evaluated mucuna and pueraria with and without burning the fallow biomass in an annual sole maize crop relay system against the burned and retained natural fallow. Over 14 consecutive years, biomass burning did not cause lower maize grain yields in any of the fallow types, on the contrary, the economically important marketable cob yields were higher when biomass was burned (mulched 2.10 cobs m^{-2} vs. 2.26 cobs m^{-2} when burned, $p < 0.07$). After cover crop fallow, maize grain yields were significantly higher than after natural fallow (1.92 Mg ha^{-1}) over the 14 years, with maize yields in the pueraria treatment (2.63 Mg ha^{-1}) out yielding those in the mucuna treatment (2.28 Mg ha^{-1}). Maize produced 1.92 cobs m^{-2} in natural fallow, significantly less than in the mucuna (2.23 m^{-2}, $p < 0.013$) and the pueraria (2.39 m^{-2}, $p < 0.001$) fallow. Introducing mucuna or pueraria cover crops into slash and burn systems appears as a suitable measure to increase yields without changing the land preparation approach.

Keywords: Cover crops; Maize; No-input agriculture; Biomass burning; Mulching; Pueraria; Mucuna

Introduction

In West and Central Africa, maize is rapidly gaining importance, partly because the poultry industry, feed millers and breweries require large quantities of dry grain. Fresh cob sales are a convenient way to generate income early in the growing season, especially in urban and peri-urban areas. Maize is a nitrogen-demanding and nitrogen-responsive crop (Hauser and Nolte, 2002). In many tropical countries, especially where smallholders' access to N fertiliser is limited, maize has been the target crop for planted leguminous fallow systems. Many examples from West and Central Africa are compiled in Carsky *et al.* (2000). These fallows appear capable to provide more N to the crop than the traditionally used natural fallow. However, there is limited information on the long-term productivity of rotational leguminous cover crop–maize systems (Hauser *et al.*, 2008).

In many West and Central African areas, early maturing maize is the first food harvested from first season fields. In southern Cameroon, farmers have recognised that green cobs from sole maize crops are an easily marketable product with a good potential to increase revenue. The crop is known to have a low labour requirement, compared with the typical groundnut/cassava/maize intercrop grown for subsistence (Büttner, 1996). However, most maize is still planted after natural fallow and because fertiliser use is low, at plant densities considerably lower than recommended. Fertiliser cost is considered high and farmers encounter difficulties with purchase and transport. Furthermore, the knowledge of efficient fertiliser use is insufficient at the village level and farmers are very suspicious of fertiliser effects on crop quality and long-term soil productivity (Büttner, 1996).

The ability of *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* to grow and fix N on the relatively poor Acrisols of southern Cameroon has been shown earlier (Hauser and Nolte, 2002; Hauser *et al.*, 2002, 2008). However, the advantages of N-fixing leguminous cover crops may be obliterated when using the traditional slash and burn land preparation because virtually all biomass N is lost. Considering that most farmers in the southern Cameroonian forest zone do not invest in soil fertility (Büttner and Hauser, 2003), but seek labour-saving methods of crop production (Duindam and Hauser, 2011), it is expected that slash and mulch systems will not be easily adopted unless crop yields are substantially higher in mulched systems. Farmers usually burn all biomass to minimise labour (Büttner and Hauser, 2003). Thus, if cover crops are introduced, their benefits could potentially be reduced or lost if the traditional labour-saving slash and burn is used. Furthermore, farmers are not accustomed to slash and mulch systems and there is insufficient information on how mulch layers affect labour requirements, weed growth, pests and diseases and maize yields. Very little experience has been gathered on the feasibility of cover crop mulch systems and their effects on maize yields in humid Africa (Hauser *et al.*, 2002).

In addition to an improved soil nitrogen status, herbaceous legume fallow may have other positive effects on soil fertility maintenance, such as erosion and compaction control and weed suppression. Sole maize crops respond positively to nitrogen released from a decomposing cover crop mulch layer (Anthofer and Kroschel, 2002). The potential of mucuna for soil fertility maintenance and crop yield increases has been demonstrated under humid conditions elsewhere (Carsky *et al.*, 1998; Hairiah and van Noordwijk, 1989; Hamadina *et al.*, 1996; Ile *et al.*, 1996; Vine, 1953). From the humid forest zone of the Congo basin, information on maize yields and soil fertility responses to herbaceous legumes are rare (Hauser and Nolte, 2002; Hauser *et al.*, 2002; Ile *et al.*, 1996) and none of the recent publications reports results on biomass burning versus mulching.

This experiment was established in 1993 and cropped for 2 years (1994 and 1995) to determine the effect of three fallow types: *Mucuna pruriens* var. *utilis, Pueraria phaseoloides* and natural regrowth. After a fallow phase in 1996, the experiment was pursued for another 14 years with biomass management by burning versus retention as an additional treatment to: (1) evaluate the maize grain yield response to the three different fallows (pueraria, mucuna, natural fallow regrowth) and the biomass management (slash and burn vs. slash and mulch), (2) obtain partial N balances for the different systems, (3) monitor weed and fallow vegetation species composition and biomass and (4) monitor soil chemical and physical properties to assess the systems' sustainability and stability or resilience over a longer phase of cropping. This paper will treat the maize grain yield responses, and topics 2, 3 and 4 will be published in companion papers.

Some results of the first years (1997–2000) of the experiment have been published, showing that soil organic matter was of better quality under the cover crops than under natural fallow, with more labile organic matter of a higher N concentration and burning biomass had no effect on organic matter quality (Koutika *et al.*, 2001). Maize grain yields were in 2 out of the first 4 consecutive years higher after leguminous fallow. In 1 year, marketable cob and grain yield were higher after burning and over the 4 years, the sum of grain yields over the 4 years was higher when biomass was burned (Hauser *et al.*, 2002).

This paper reports the performance of the maize crop over a trial duration of 18 years during which maize was cropped in 16 years, and maize yield data are available for 15 years. Maize was consecutively cropped for the last 14 years (1997–2010), focussing on the marketable cob and maize grain yield responses to the three different fallows and the biomass management to assess the potential of the technology to be adopted by farmers based on the traditional slash and burn system.

Material and Methods

Site, climate and soil

The experiment was carried out in southern Cameroon at the IITA Humid Forest Eco-regional Centre, Mbalmayo (3°27’56.83” N, 11°29’12.63” E), about 665 masl. Average annual precipitation is 1513 mm in a bimodal distribution. Rains start in mid-March. From mid-July until the end of August is a short dry season. The main rainy season is from September to the middle of November. The soil is classified as an isohyperthermic Typic Kandiudult (Hulugalle and Ndi, 1993).

Land-use history

The land was manually cleared from secondary forest in 1990. In 1991/92, the land was cropped to cassava, thereafter left to natural regrowth. On 7 June 1993 natural regrowth, dominated by *Chromolaena odorata*, was slashed and three fallow types: natural fallow regrowth, *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides*, were established. Mucuna and pueraria were seeded 10 days after slashing. The experiment was initially a single-factor randomised block design with three replicates. Plots measured 13 × 7 m. In March 1994 and 1995, the legumes and the natural fallow were slashed, biomass was retained. Maize cv. CMS 8704 (90–100 days to maturity) was seeded at 0.75 × 0.25 m distance. Due to discontinued funding, the trial was left to fallow in 1996. In late February 1997, all plots were slashed manually. Plots were split into two subplots of 7 × 6.5 m. In one subplot, the biomass was retained, and in the other, the biomass was burned before seeding maize.

The trial was continued with variable levels of funding until 2010.

Cover crop and maize husbandry and harvest procedure

From 1997 to 2010, every year, between the end of March and middle of April, depending on the onset of the rainy season, maize cv. CMS 8704 (open-pollinated, 90–100 days to maturity) was seeded in a square configuration at 0.5 × 0.5 m distance with two seeds per pocket. After the maize harvest, the second season was not used for cropping as rains are heavy and crop yields poor, but left for the cover crops and natural fallow to grow. The maize variety is well adapted and is being used by farmers in southern Cameroon (Tandzi *et al.*, 2015). The maize stand was thinned to one plant per pocket at the four–six-leaf stage. If plants were missing an adequate number of plants in neighbouring pockets was retained to achieve a density of four plants m^{-2}. Maize was harvested on the centre $4 \times 4\ m = 16\ m^2$ per plot. The number of plants and cobs was counted. The total cobs were separated into marketable cobs and those not deemed to being suitable for fresh sales; the marketable cobs were counted by employed farmers who usually sell maize cobs. All cobs were husked and weighed fresh. A representative subsample of marketable and nonmarketable cobs (about 1000 g fresh) was taken, weighed and dried to constant mass. Dry cobs were shelled and grain and rachis dry matter determined to calculate dry matter grain yield. Straw yield was determined by collecting 16 stems after cob removal along the 2 diagonals of the harvested area. Stems were weighed and cut into 2 cm pieces along with an according number of husks. The cut material was mixed, a subsample was taken (about 800 gram) and dried to constant mass. Straw biomass was calculated from the dry matter of the stem and husk subsample plus the rachis mass from the cob subsample.

Mucuna and pueraria re-established after each maize harvest without being re-seeded throughout the entire lifetime of the trial.

Soil chemical properties

The soil properties at cover crop establishment in 1993 are shown in Table 1 and after the 15th maize crop in 2009 in Table 2. As of 1997, soil was sampled before slashing and burning every year

Table 1. Soil chemical properties in 1993 before the establishment of the cover crops, Mbalmayo, southern Cameroon

	1993		
Soil layer (cm)	0–5 cm	5–10 cm	10–15 cm
pH in water	6.61	6.13	6.04
Total N (g kg^{-1})	2.13	1.02	0.74
Org. C (g kg^{-1})	27.20	14.20	9.20
C/N	12.770	13.922	12.432
P (mg kg^{-1})	11.7	2.53	1.14
Ca (cmol[+] kg^{-1})	6.24	2.96	2.41
Mg (cmol[+] kg^{-1})	1.92	0.79	0.57
K (cmol[+] kg^{-1})	0.158	0.055	0.053

Adapted from Hauser *et al.* (2002).

Table 2. Soil chemical properties in 2009 before land preparation for the 15th maize crop, Mbalmayo, Cameroon

Soil depth	0–5 cm		5–10 cm		10–15 cm	
Biomass management	Burned	Retained	Burned	Retained	Burned	Retained
pH in water	6.729	6.478	6.749a	6.372b	6.682a	6.304b
Total N (%)	0.200	0.202	0.143	0.135	0.107	0.101
Org. C (%)	2.077	1.976	1.446	1.268	0.998	0.893
C/N	10.407a	9.864b	10.220a	9.353b	9.363a	8.769b
P (mg kg^{-1})	7.116	7.538	5.278	3.517	2.493	2.272
Ca (cmol[+] kg^{-1})	6.990	6.117	4.796a	3.601b	3.524	2.581
Mg (cmol[+] kg^{-1})	1.557a	1.216b	1.057a	0.756b	0.790a	0.625b
K (cmol[+] kg^{-1})	0.229	0.177	0.195	0.090	0.136	0.075

Figures within the same parameter and soil layer followed by different letters are significantly different at $p < 0.05$.

until 2009. Details of changes over time will be reported separately. Twelve soil samples per plot were taken with 100 cm^3 cores of 5 cm length, at 0–5, 5–10 and 10–15 cm depths and dried to constant mass at 60 °C to determine bulk density. After drying, the samples were ground to pass through a 0.5 mm mesh size sieve for chemical analysis. Soil pH was determined in a water suspension at a 2:5 soil/water ratio. Exchangeable Ca $^{2+}$, Mg^{2+}, K^{+} and available P were extracted by the Mehlich 3 procedure (Mehlich, 1984). Cation concentrations were determined by atomic absorption spectrophotometry and P by the malachite green colorimetric procedure (Motomizu *et al.*, 1983). Organic C was determined by chromic acid digestion and spectrophotometric procedure (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Mulvaney, 1982; Bremner and Tabatabai, 1972).

Statistical analyses

Statistical analyses were performed on untransformed data using the GLM procedure in SAS, and calculating least-square means (lsmeans). Levels of significance (p-values) for pairwise comparisons between least-square means were calculated. Levels of significance upto $p = 0.1$ are reported for pairwise comparison of treatments. Differences are referred to as significant if $p < 0.05$. In addition, the yield variables were subjected to a cluster and principal component analyses. Principal Component Analysis (PCA) with Biplot was to reveal any pattern and relationships between treatment units (a cross-classification of year, fallow type and biomass management) and variables measured (number of plants at harvest, cob density at harvest, marketable cob density, grain yield, straw yield and harvest index (HI)); and the Cluster Analysis (CA) was to form exclusive groupings or clusters of treatment units. These multivariate tool procedures (Afifi and Clark, 1990; Anderberg, 1973; Ward, 1963) were applied to treatment means over replications.

Results

Maize cob production

Over the years 1995–2010, the fallow type did not affect the cob density. On average, maize in the control produced 3.45 cobs m^{-2} and in the mucuna and pueraria system, it produced 3.48 and 3.60 cobs m^{-2}, respectively. In 1995, the cob production was higher than in all the following years with an average of 6.31 versus 3.31 cobs m^{-2}. Only in 2000 and 2002, significant effects of fallow were found with maize in the mucuna system producing 4.00 cobs m^{-2} in 2000, significantly more than in the control (3.52, $p < 0.0004$) and in 2002, maize in the control producing significantly more cobs (2.97 cobs m^{-2}) than in both cover crop systems (1.95 cobs m^{-2}, $p < 0.034$).

From 1997 to 2010, the biomass management (slash and burn vs. slash and mulch) inconsistently affected the number of cobs m^{-2} with overall more cobs produced when burned (3.39 cobs m^{-2}) than when mulched (3.22 cobs m^{-2}, $p < 0.077$). In 3 years, biomass management had a significant effect on cob density: in 1997 and 1998, more cobs were produced after burning (3.46 and 4.48, respectively) than when biomass was retained (3.18 and 2.95, respectively, $p < 0.02$). Yet, in 2003, more cobs were produced when biomass was retained (3.51) than after burning (2.69, $p < 0.007$). Across the years, differences in cob densities between fallow types and biomass management were negligible.

Marketable cob production

Over the years 1995–2010, both legume cover crop fallows had a significant positive effect on the marketable cob density (Table 3) with 2.33 and 2.49 marketable cobs m^{-2} in the mucuna and pueraria system, respectively versus 1.95 marketable cobs m^{-2} in the control. In both legume systems, this advantage was significant in 5 years and in one additional year in the pueraria system only.

On average from 1997 to 2010, the number of marketable cobs m^{-2} was marginally different between biomass retained (2.10 marketable cobs m^{-2}) and biomass burned (2.26 marketable cobs m^{-2}, $p < 0.071$) (Table 4). In 1998 and 2008, significantly more marketable cobs m^{-2} were produced after biomass burning than when biomass was retained. In 2003, more marketable cobs m^{-2} were produced when biomass was retained.

Table 3. Marketable maize cob density (cobs m^{-2}) in three fallow types, means across biomass management treatments, Mbalmayo southern Cameroon

	Fallow type			P diff		
Year	Natural	Mucuna	Pueraria	Nat. versus Muc	Nat versus Pue	Muc versus Pue
1995*	2.347	3.763	3.887	0.0123	0.0092	ns
1997	2.089	2.637	2.793	0.0044	0.0009	ns
1998	2.031	2.188	2.146	ns	ns	ns
1999	0.792	1.656	2.333	0.0114	0.0003	0.0359
2000	2.365	2.656	2.427	ns	ns	ns
2001	2.810	2.498	2.699	ns	ns	ns
2002	0.448	0.923	1.161	ns	0.0298	ns
2003	2.177	2.396	2.488	ns	ns	ns
2004	3.667	3.490	3.521	ns	ns	ns
2005	1.625	2.202	2.427	0.0234	0.004	ns
2006	0.990	1.073	1.292	ns	ns	ns
2007	2.531	3.146	3.031	ns	ns	ns
2008	1.094	1.771	2.333	0.0144	0.0003	0.034
2009	1.958	2.010	2.281	ns	ns	ns
2010	2.375	2.542	2.552	ns	ns	ns
Mean	1.953	2.330	2.491	0.0127	0.0009	ns

*In 1995, no biomass burned versus retained treatments.

Table 4. Marketable cob density (cobs m^{-2}) at harvest in biomass retained and burned fallow types, Mbalmayo, southern Cameroon

Year	Retained	Burned	P diff
1997	2.40	2.62	ns
1998	1.81	2.43	0.0257
1999	1.52	1.67	ns
2000	2.33	2.63	ns
2001	2.79	2.55	ns
2002	0.95	0.74	ns
2003	2.63	2.08	0.0200
2004	3.32	3.80	ns
2005	1.92	2.25	0.0881
2006	1.30	0.94	ns
2007	2.73	3.08	ns
2008	1.75	1.72	ns
2009	1.66	2.51	0.0102
2010	2.28	2.70	ns
Mean	2.10	2.26	0.0711

Maize grain yield

Across 15 years for which yield data are available, the legume cover crops had a significant grain yield advantage over the natural fallow of plus 0.38 Mg ha^{-1} $year^{-1}$ in the mucuna system ($p < 0.0242$) and plus 0.79 Mg ha^{-1} $year^{-1}$ in the pueraria system ($p < 0.0004$). In 1995, fallow type had a significant effect on grain yield with 1.467 Mg ha^{-1} in the natural fallow, 2.133 Mg ha^{-1} after mucuna and 3.360 Mg ha^{-1} after pueraria fallow. The maize grain yield after pueraria was significantly higher than after natural fallow ($p < 0.0059$) and after mucuna ($p < 0.0256$). In 14 years following the fallow phase of 1996, fallow type affected maize grain yields in 8 years (Figure 1). The average maize

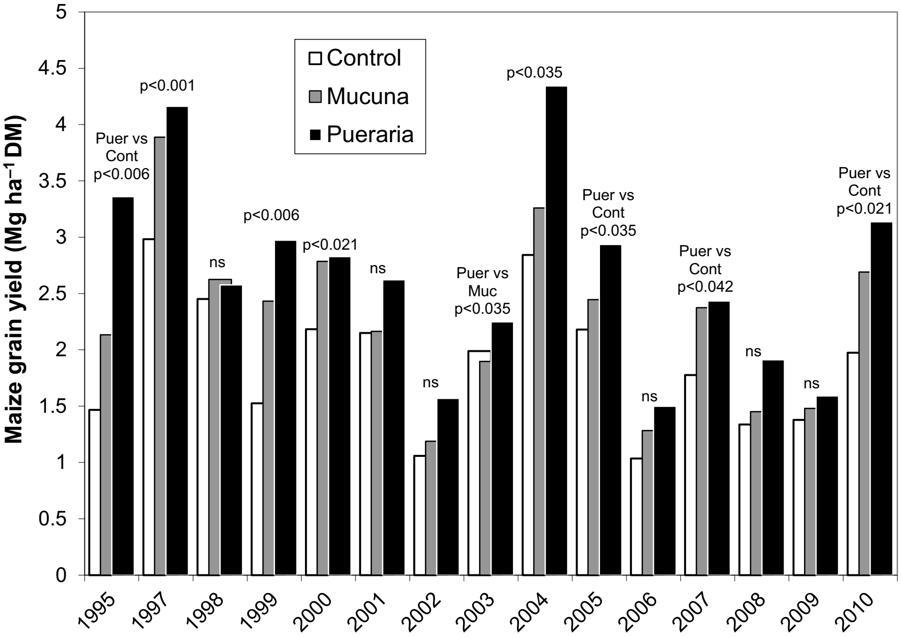

Figure 1. Maize grain yields (Mg ha^{-1} DM) over 15 years in three fallow types, means across biomass management treatments, Mbalmayo, southern Cameroon. Note: Single *p*-values above columns indicate the level of significance of both cover crops versus the control.

Table 5. Maize grain yield (Mg ha^{-1} DM) after burning versus retention of the fallow biomass, means across three fallow types, Mbalmayo, southern Cameroon

Year	Retained	Burned	P diff
1997	3.59	3.77	ns
1998	2.20	2.91	0.0267
1999	2.20	2.43	ns
2000	2.57	2.62	ns
2001	2.63	1.99	0.045
2002	1.38	1.16	ns
2003	2.33	1.76	0.0007
2004	3.49	3.48	ns
2005	2.53	2.51	ns
2006	1.43	1.11	ns
2007	2.12	2.27	ns
2008	1.47	1.67	ns
2009	1.04	1.92	0.0033
2010	2.15	3.05	0.027
Mean	2.22	2.33	ns

grain yield difference between the mucuna and pueraria system (0.41 Mg ha^{-1} $year^{-1}$) was significant ($p < 0.0299$). These annual differences translated into 5.77 Mg ha^{-1} more grain yield in the mucuna and 11.86 Mg ha^{-1} more grain yield in the pueraria system than in natural fallow, cumulated over 15 years (including 1995), with the pueraria cover crop system producing 6.09 Mg ha^{-1} more maize grain than the mucuna system.

Maize grain yield was inconsistently affected by the biomass management. Across the years 1997–2010, the average grain DM yield when burned (2.33 Mg ha^{-1}) was not significantly different from biomass retained (2.22 Mg ha^{-1}) (Table 5). Maize grain yield advantages were significant in 2 years when biomass was retained and in 3 years when biomass was burned.

Neither the CA nor the PCA revealed clusters of similar responses or factors that had consistent effects overtime on the grain and cob yields.

Maize plant density

Maize plant density at harvest was affected by the biomass management: in 3 years, plant density was higher after burning (1997, 1998 and 2005) and once higher when biomass was retained (2007) (Table 6). In some years, the plant density exceeded the target density of 4 m^{-2} due to uncertainty of survival at the time of thinning (i.e. more plants were retained than needed) and plants that survived the thinning because they were not uprooted but cut off and able to sprout. The fallow type did not affect plant density significantly and there were no fallow × biomass management interactions.

Maize straw yield

Maize straw yields were not affected by the biomass management across the 14 years after 1996 (retained 4.22 vs. burned 4.30 Mg ha^{-1}). In 2 years, biomass retention caused significantly higher straw yields and in 1 year, straw yield was higher after burning (not shown). The fallow type affected straw production, yet only in pueraria fallow were straw yields significantly higher than in natural fallow in 4 of the 14 years (Figure 2). Across the years, maize produced more straw in both cover crop systems than in the natural fallow. Unlike the grain yield, the straw yield showed a strong decline with time from 1995 to 2002 with a reduction of around 1 Mg ha^{-1} $year^{-1}$ in all systems and remained thereafter on a level of 2–4 Mg ha^{-1} with a much smaller decline of 0.17–0.20 Mg ha^{-1} $year^{-1}$. Across 15 years, straw production declined by 0.41 Mg ha^{-1} $year^{-1}$ in the pueraria system ($r^2 = 0.613$), 0.39 Mg ha^{-1} $year^{-1}$ in the mucuna system ($r^2 = 0.542$) and 0.35 Mg ha^{-1} $year^{-1}$ in the control ($r^2 = 0.557$).

Table 6. Maize plant density (plants m^{-2}) at harvest in biomass retained and burned fallow types, Mbalmayo, southern Cameroon

Year	Retained	Burned	P diff
1997	3.34	3.78	0.0149
1998	3.68	5.03	0.0381
1999	4.37	3.69	0.0585
2000	3.91	4.13	0.086
2001	3.77	3.59	ns
2002	3.21	3.02	ns
2003	3.73	3.78	ns
2004	3.69	4.45	0.0863
2005	3.80	4.11	0.0419
2006	2.47	2.24	ns
2007	3.97	3.81	0.0479
2008	3.34	3.00	ns
2009	3.47	3.38	ns
2010	3.67	3.70	ns
Mean	3.60	3.69	ns

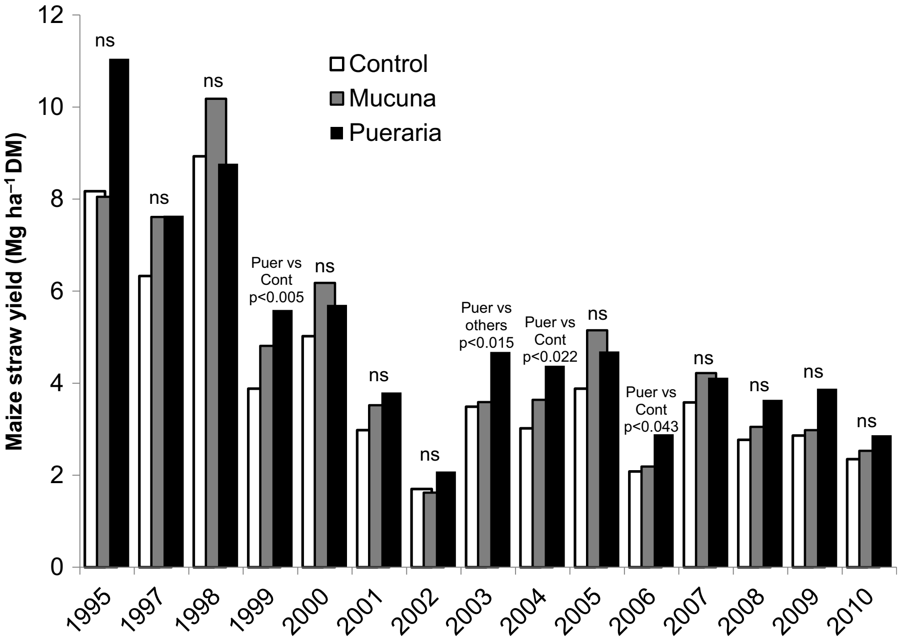

Figure 2. Maize straw yields (Mg ha^{-1} DM) over 15 years in three fallow types, means across biomass management treatments, Mbalmayo, southern Cameroon.

Harvest index

The HI was not affected by the fallow type in any individual year, yet across the years, it was significantly higher in the pueraria system than the natural fallow (38.3 vs. 35.9; $p < 0.0054$) and the mucuna system (36.6, $p < 0.0325$). Biomass management had an inconsistent effect on the HI with a significant advantage of burning in only 1 year and an overall insignificant advantage at 37.7 (burned) versus 36.2 (retained).

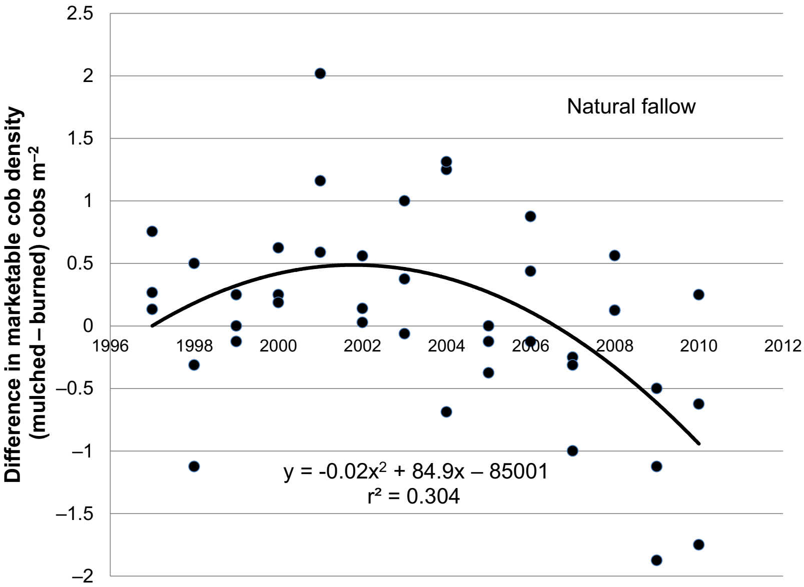

Figure 3. Changes of the difference between the marketable cob densities in the mulched versus the biomass burned treatments of the natural fallow system over 14 years.

Correlations

The marketable cob densities in burned and retained systems were closely correlated ($r^2 = 0.759$).

Yield trends over time

Over 15 years, there was no significant trend in the marketable cob density in the different biomass management systems. Regressions had slopes of –0.0048 and 0.0082 (Mg ha^{-1} year^{-1}) in biomass retained and burned systems, respectively, and r^2 was 0.0009 and 0.0005. Within the fallow systems, regressions had slopes <0.0012 (Mg ha^{-1} year^{-1}) and $r^2 = 0.0002$. In none of the individual, fallow × biomass management treatments was a significant trend found over time. However, the differences between the mulched and burned biomass treatments in the natural fallow were correlated by a second-order polynomial function (Figure 3). In the mucuna and pueraria systems, similar functions with the same pattern were found, yet with insignificant coefficients of determination (not shown) and the function being generally in the negative range, i.e. with generally more marketable cobs in the burned than in the mulched system.

No significant trend in maize grain yields over the consecutive 14 years (1997–2010) could be discerned across all treatments, or for the individual biomass management treatments, or the fallow types. However, all trends were negative. Two individual treatments: the natural fallow and the mucuna fallow with biomass retained had a significant negative maize grain yield trend with time, with the following equations:

$$\text{Natural fallow biomass retained : yield} = -0.1075 \times \text{years} + 217.4; r^2 = 0.3255; p = 0.0331,$$

$$\text{Mucuna fallow biomass retained : yield} = -0.0849 \times \text{years} + 172.3; r^2 = 0.2982; p = 0.0434.$$

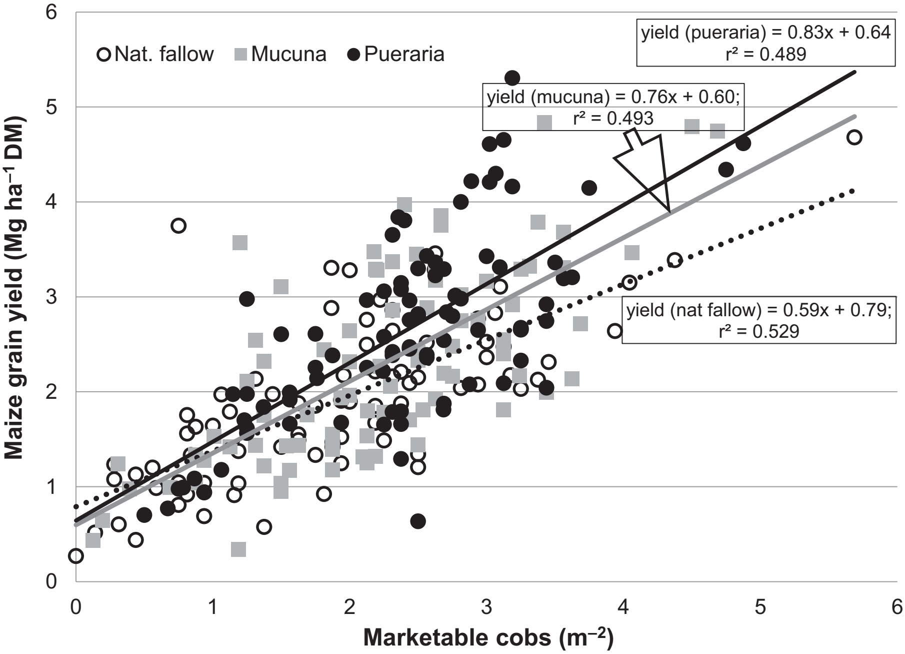

Figure 4. Relationship between the number of marketable cobs m^{-2} and the dry matter maize grain yield over 14 consecutive years.

Within crop correlations

Maize plant density was significantly, yet weakly correlated with the cob density ($r^2 = 0.479$, $p < 0.0001$), the marketable cob density ($r^2 = 0.292$, $p < 0.0001$) and grain yield ($r^2 = 0.234$, $p < 0.0001$). The total cob density was weakly correlated with the grain yield ($r^2 = 0.377$, $p < 0.0001$). The closest correlation was found between the marketable cob density and the grain yield ($r^2 = 0.509$, $p < 0.0001$). Separating the data by biomass management showed that the regression in burned and biomass retained treatments were very similar, yet the r^2 was higher in the biomass burned system than in the biomass retained system:

$$\text{Biomass burned : grain yield} = 0.77 \times \text{marketable cob density} + 0.60;$$

$$r^2 = 0.584; p < 0.0001,$$

$$\text{Biomass retained : grain yield} = 0.70 \times \text{marketable cob density} + 0.75;$$

$$r^2 = 0.418; p < 0.0001.$$

Separating the data by the fallow type (across biomass management) showed that in the legume fallows, the slope of the regression was steeper than in the natural fallow, with minor differences between the regression coefficients (Figure 4) and the following equations:

$$\text{Natural fallow : grain yield} = 0.59 \times \text{marketable cob density} + 0.79; r^2 = 0.529; p < 0.0001,$$

$$\text{Mucuna fallow : grain yield} = 0.76 \times \text{marketable cob density} + 0.60; r^2 = 0.493; p < 0.0001,$$

$$\text{Pueraria fallow : grain yield} = 0.83 \times \text{marketable cob density} + 0.64; r^2 = 0.489; p < 0.0001.$$

Discussion

Marketable cob yield

For farmers in the humid forest zone, maize grain production is often of secondary importance and would largely serve building dry food reserves for subsistence purposes. Climatic conditions are not favourable to dry large quantities rapidly to support the sales of dry grain. Fresh cob sales have over the last decades gained importance (Hauser *et al.*, 2008) and with growing urban populations, fresh cobs are one of the first products farmers can send to market. In so far, marketable cob yields and grain yields have to be regarded as similarly important, whereby with proximity to markets, the fresh cob sales are likely to be more important.

Over 15 years, the mucuna and pueraria systems produced 0.38 and 0.54 more cobs m^{-2} than the natural fallow, respectively, which would translate into an advantage of 3800 and 5400 more cobs ha^{-1} $year^{-1}$. At farm gate prices of around 50 FCFA per cob (1 US$ = 575 FCFA), this translates into an additional income of US$330 (mucuna) to US$470 (pueraria) ha^{-1} $year^{-1}$. Considering farmers' fields being often 0.15–0.25 ha (Duindam *et al.* 2010), the annual gains may appear small, yet they are realised at no additional cost compared with the natural fallow system. In southern Cameroon, yet north of the trial described here, Duindam *et al.* (2010) demonstrated in cassava/maize intercropping that pueraria fallow actually reduced the labour requirements and attained the highest labour productivity through combined yield increases and reduced labour.

Advantages in marketable cob production were found at a site in southern Cameroon on an Acrisol with less favourable soil properties than in this trial, with maize producing 38.5% more marketable cobs in the mucuna system than the natural fallow (Hauser *et al.*, 2008). There, similar to this trial, the advantage was only significant in 1 of the 7 consecutive years.

In the trial reported here, biomass management had a small effect on the mean density of marketable cobs, with only 7.6% more marketable cobs when biomass was burned and was in 2 years significantly higher after burning and once significantly higher when biomass was retained. In trials on Acrisol in a low land-use intensity area (Hauser *et al.*, 2008), biomass management had a stronger effect on marketable cobs with 20 and 36.3% more marketable cobs when mucuna and natural fallow biomass were burned, respectively. Where land-use intensity was higher, burning biomass had negative effects on the marketable cob production (Hauser *et al.*, 2008).

Although the difference in the average marketable cob production between biomass retained and burned was insignificant, the absence of a significant negative trend in all fallow systems when biomass was burned may indicate that burning biomass does not have a negative impact on the productivity of the systems. In the trial reported here, none of the treatments had a significant trend over time in the marketable cob production.

Looking at the effects of biomass management by fallow type, it was revealed that the difference of the marketable cob density (cob density in mulched – cob density in burned) in the natural fallow followed a second-order polynomial function ($r^2 = 0.304$) (Figure 3) increasing initially to +0.5 cobs m^{-2} and after 2002 decreasing to −1 cob m^{-2}, which indicates that the marketable cob density had an increasingly positive response to biomass burning with an increasing number of cropping years. Functions with the same pattern were found in the mucuna and pueraria systems corroborating this trend despite their low r^2 of 0.064 and 0.070, respectively. However, the functions in the cover crops were in the negative range, i.e. with generally more marketable cobs in the burned than in the mulched system, reflecting the overall advantage of burning biomass becoming more positive with an increasing number of cropping years.

This is an unexpected result, which may need to be evaluated in connection with the weed incidence and the type of weeds found in the different biomass management systems. Generally, burning has a controlling effect on early weed infestation, yet the relatively low amounts of biomass are unlikely to affect any seeds of the cover crops and weed species, rhizomes (weeds) and rootstocks (pueraria) in the soil as temperatures usually do not exceed 50 °C (Hauser, 2006). Thus, the removal of biomass by burning may have reduced the weed density by eliminating weed seeds at the soil surface and facilitating the manual weeding by providing a clean soil surface. An additional positive effect of burning may be the provision of water-soluble cations from the ash, yet, again due to the low amounts of biomass, this effect is likely to be marginal. An additional reason for the absence of a negative effect of biomass burning may be caused by the cover crops shedding most of the leaves before and during the dry season and soil fauna incorporating these materials, thus preventing them from being affected by the burn. However, no quantitative information was collected on such potential processes.

Maize grain and straw yield

Advantages in maize grain yields in pueraria (Tian *et al.*, 2000, 2001) and mucuna fallow systems (Carsky *et al.*, 2001) have been demonstrated across West and Central Africa. The maize grain yields attained in this trial, in an environment not particularly suitable for maize, are well within the range of those attained in other African Countries (1.13–2.03 Mg ha^{-1}) (Gustafson *et al.*, 2014) except the Republic of South Africa. The results of this study show that the cover crops mucuna and pueraria can lift mean yields over at least 15 years above those attained in natural fallow systems. A long-term average advantage of 0.38 (mucuna) and 0.79 (pueraria) Mg ha^{-1} year^{-1} of grain would improve food security and income. However, the fact that this advantage is not realised every year remains a shortfall of the system. Although in only 1 year, the natural fallow system produced marginally more grain than the mucuna system, the frequent nonsignificant differences require further research.

In another trial conducted over 7 consecutive years in southern Cameroon, Hauser *et al.* (2008) found higher grain yields in the mucuna system compared with natural fallow in 6 years, yet only in 1 year was the difference significant at $p < 0.05$. Thus, this ‘unreliable’ effect of the cover crops may not be unusual if trials run over longer periods. In the short term, i.e. in the first years after cover crop establishment, the cover crops have quite regularly significant positive effects on grain yield (Hauser *et al.* 2008).

The average grain yield over time, like the marketable cob production, was not significantly affected by the biomass management. Biomass management had a more inconsistent effect than the fallow type: two significant higher grain yields when biomass was retained and three higher grain yields when biomass was burned. In another trial in southern Cameroon over 7 years, burning biomass had in all years a positive effect on grain yield, and in 2 years, it was significant (Hauser *et al.*, 2008). In trials over short periods and in sites with higher land-use intensity biomass retention has usually positive effects (Norgrove *et al.*, 2003).

There are no directly comparable trials over a similar length of time. From northern Ghana, Agyare *et al.* (2006) reported declining maize grain yields in several maize/grain-legume rotations, a system likely to be somewhat similar, except for the fact that maize was grown on the same plot every other year and legume grain was removed. However, as in the results reported here, the yield decline over time in the trials in northern Ghana was not consistent, with strong declines in the first 4 years and levelling out over the following 8 years.

The maize straw production in both cover crop systems was on average over 15 years significantly higher than in the natural fallow. However, the difference between mucuna and natural fallow was in none of the years significant, while the pueraria system outperformed the natural fallow in 4 years. The strongly differentiated reduction in straw yields over time and the much slower decline in the later 7 years may indicate that in the first years, the straw production was benefitting from the higher initial soil fertility.

Maize plant density and cob production

In the first 4 years of this trial, the variability in plant density appeared to affect the grain yields and attaining the target density was easier in the burned system than when biomass was retained (Hauser *et al.*, 2002). However, in the later years, except for 2006, the variability of the plant density was relatively low from year to year and between biomass management systems within years. Thus, the cover crops do not affect the crop establishment and the related labour requirements. Retaining biomass is a more critical issue for plant establishment and regulating plant density. Although a direct impact of mulch on the establishment and early plant losses could not be shown in parallel trials (Hauser, 2007), other operations, specifically weeding, increase the risk of maize plant damages and losses. The often fibrous mulch material would either need to be lifted off the soil when using the hoe to weed or it is simply pushed around by the hoe and may hit, break or uproot young maize plants. Although such damages and losses were not determined, they may have contributed to the slightly lower overall pant density in the biomass retained system. Cob production as well was little affected by the fallow type and biomass management. This may indicate that the crop produced cobs independent of the nutrient supply in the different systems and that grain yield differences were caused by size and mass of cobs.

Prospects of adoption

Using the cover crops *Pueraria phaseoloides* and *Mucuna pruriens* var. *utilis* in the humid forest zone of Cameroon resulted in significant maize grain yield gains over 15 years of maize production. The relatively low number of years in which the grain yield advantage in the cover crop systems was significant may appear to be a drawback, yet for farmers, such statistical considerations may not matter as long as they have discernibly higher yields. Here, these higher yields were attained in a system not fundamentally different from the common ‘slash and burn’ approach. The advantage of the system is its labour efficiency as the fire removes obstacles and reduces weed seeds at the soil surface, thus facilitating crop management (Hauser and Norgrove, 2013). Although ‘politically incorrect’ in a world that needs to reduce CO_2 emissions, it is difficult to justify a ‘slash and mulch’ system that does not offer any advantage to food production, food security and income generation of poor smallholder farmers. Considering that only the biomass produced within the cropping and fallow cycle is burned, the system may well be carbon neutral, while increasing crop production. Temporary negative impacts on air quality when burning biomass on large tracts of land would need to be considered in case this system is scaled up.

In a labour-intensive livelihood system, it is not to be expected that a system likely to require more labour in the long term and being more tedious in crop management will be accepted. In Indonesia, these advantages of burning were well documented by farmers establishing rubber plantations (Ketterings *et al.*, 1999). Further, the loss of biomass by burning the cover crops may need to be balanced against the continued use of natural fallow systems, that after some time become unproductive (low yields and high labour requirements), are abandoned and new land is taken into cultivation by forest clearing. Depending on the forest age, the latter may release more CO_2 in a single burn than annual burning of the cover crops over several years. Although not quantified in this trial, we observed that the burned systems are easier to seed and to weed due to the absence of litter and mulch. Farmers are unlikely to give up burning as they often do not try to maximise yields but to reduce labour. This clearly favours a slash and burn system. The data on soil properties, to be published in a companion paper, will contribute towards an assessment of the systems’ sustainability.

Conclusion

The insignificant grain yield declines over time should encourage the dissemination of the cover crop relay fallow system with biomass burning. To address the variation between years, further research is required and should look into the potential of supplementing nutrients by adding fertiliser, specifically P and K, which are low in these Acrisols, to enhance maize growth and yield and to support legume growth and N fixation. Although not labour neutral, shallow incorporation of cover crop biomass through manual tillage (no-till in this trial) may increase the effects on maize performance. Alternatively, small-scale mechanisation, although cost-intensive, might retain a low labour requirement while benefiting from biomass incorporation before seeding maize or other crops. Livestock integration would add value to the cover crops. In cotton systems of Burkina Faso, Kotou *et al.* (2016) reported that mucuna adoption was higher in households with more livestock. Although in the humid forest zone of Cameroon large livestock is not sustainable, small ruminants and livestock rodents (guinea pigs and cane rats) would benefit from the protein-rich cover crop foliage. However, consequences of grazing or cut and carry cover crop biomass would need to be investigated for their consequences on the following maize crops.

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References

Afifi A.A. and Clark V. (1990). *Computer Aided Multivariate Analysis*, 2nd Edn, New York: Chapman and Hall.

Agyare W.A., Clottey V.A., Mercer-Quarshie H. and Kombiok J.M. (2006). Maize yield response in a long-term rotation and intercropping systems in the guinea savannah zone of Northern Ghana. *Journal of Agronomy* **5**, 232–238.

Anderberg M.R. (1973). *Cluster Analysis for Applications.* New York: Academic Press.

Anthofer J. and Kroschel J. (2002). Partial macronutrient balances of mucuna/maize rotations in the forest savannah transitional zone of Ghana. In Vanlauwe B., Diels J., Sanginga N. and Merckx R. (eds), *Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice.* Wallingford: CABI, pp. 87–96.

Bremner J.M. and Mulvaney C.S. (1982). Inorganic nitrogen. In Page A.L., Miller R.H. and Keeney D.R. (eds), *Methods of Soil Analysis Part 2.* Madison: American Society of Agronomy, pp. 595–624.

Bremner J.M. and Tabatabai M.A. (1972). Use of an ammonia electrode for determination of ammonium in Kjeldahl analysis of soils. *Communications in Soil Science and Plant Analysis* **3**, 71–80.

Büttner U. (1996). Soil nutrient management practices of farmers in the humid forest region of Southern Cameroon. Unpublished MSc. thesis, Faculty of Rural Development, Universität Göttingen, Germany.

Büttner U. and Hauser S. (2003). Farmers' nutrient management practices in indigenous cropping systems in southern Cameroon. *Agriculture, Ecosystems and Environment* **100**, 103–110.

Carsky R.J., Becker M. and Hauser S. (2001). Mucuna fallow for the maintenance and restoration of soil fertility of tropical cropping systems: Potential and limitations. SSSA Special Publication no. 58, Sustaining Soil Fertility in West Africa. pp. 111–135.

Carsky R.J., Eteka A.C., Keatinge J.D.H and Manyong V.M. (2000). Cover crops for natural resource management in West Africa. Proceedings of a workshop organized by IITA and CIEPCA, 26–29 October 1999. International Institute of Tropical Agriculture, Ibadan Nigeria. 316 pp.

Carsky R.J., Tarawali S.A., Becker M., Chikoye D., Tian G. and Sanginga N. (1998). Mucuna – herbaceous cover legume with potential for multiple uses. Resource and Crop Management Research Monograph Vol. 25. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Duindam J.W., Fermont A. and Hauser S. (2010). Pueraria fallows improve labour efficiency and productivity of cassava systems in the forest zone of Cameroon. Proceedings, Tropentag 2010, September 14–16, Zurich, Switzerland. Available at https://www.tropentag.de/2010/abstract.php?code=oMZddn1t (accessed 24 November 2020).

Duindam J.W. and Hauser S. (2011). Prioritizing research efforts to increase on-farm income generation: the case of cassava-based farmers in Peri-Urban Southern Cameroon. In Bationo A., Waswa B., Okeyo J. M., Maina F. and Kihara J. (eds), *Innovations as Key to the Green Revolution in Africa.* Dordrecht: Springer, pp. 913–919.

Gustafson D.I., Jones J.W., Porter C.H., Hyman G., Edgerton M.D., Gocken T., Shryock J., Doane M., Budreski K., Stone C., Healy D. and Ramsey N. (2014). Climate adaptation imperatives: untapped global maize yield opportunities. *International Journal of Agricultural Sustainability* **12**, 471–486.

Hairiah K. and van Noordwijk M. (1989). Root distribution of leguminous cover crops in the humid tropics and effects on a subsequent maize crop. In Van der Heide J. (ed.), *Nutrient Management for Food Crop Production in Tropical Farming Systems.* Haren, The Netherlands: Institute for Soil Fertility; Malang, Indonesia: Universita Brawijaya, pp. 157–169.

Hamadina M.K., Henrot J., Isirimah N.O. and Tariah N. (1996). Potential benefits of a leguminous cover crop and a slow decomposing mulch in fallow management on a degraded soil of the humid tropics. In Neeteson J.J. and Henrot J. (Eds), *The Role of Plant Residues in Soil Management for Food Production in the Humid Tropics.* Haren, The Netherlands: DLO-AB, pp. 81–96.

Hauser S. (2006). Soil temperatures during burning of large amounts of wood, effects on soil pH and subsequent maize yields. Proceedings of the Tropentag 2006, University of Bonn, October 11–13, 2006, 4 pp.

Hauser S. (2007). Maize yield response to mulch, burning and insecticide application on an Ultisol. Proceedings of the Tropentag 2007, University of Kassel and University of Göttingen, October 9–11, 2007. 6 p.

Hauser S., Bengono B. and Bitomo O.E. (2008). Short- and long-term maize yield response to *Mucuna pruriens* and *Pueraria phaseoloides* relay fallow and biomass burning versus mulching in the forest zone of southern Cameroon. *Biological Agriculture and Horticulture* **26**, 1–17.

Hauser S., Henrot J. and Hauser A. (2002). Maize yields in a *Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides* relay fallow system on an Ultisol in southern Cameroon. *Biological Agriculture and Horticulture* **20**, 243–256.

Hauser S. and Nolte C. (2002). Biomass production and N fixation of five *Mucuna pruriens* varieties and their effect on maize yields in the forest zone of Cameroon. *Journal of Plant Nutrition and Soil Science* **165**, 101–109.

Hauser S. and Norgrove L. (2013). Slash-and-Burn Agriculture, Effects of. In Levin S. A. (ed.), *Encyclopedia of Biodiversity*, 2nd Edn. Waltham, MA: Academic Press. Volume **6**, pp. 551–562.

Heanes D.L. (1984). Determination of organic C in soils by an improved chromic acid digestion and spectro-photometric procedure. *Communications in Soil Science and Plant Analysis* **15**, 1191–1213.

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

Ile E., Hamadina M.K., Henrot J. and Tariah N.M. (1996). Residual effects of a previous *Mucuna pruriens* crop on the performance of maize. In J.J. Neeteson and J. Henrot (eds), *The Role of Plant Residues in Soil Management for Food Production in the Humid Tropics*. Haren, The Netherlands: AB-DLO, pp. 97–105.

Ketterings Q.M., Wibowo T.T., van Noordwijk M. and Penot E. (1999). Farmers' perspective on slash-and-burn as a land clearing method for small-scale rubber producers in Sepunggur, Jambi Province, Sumatra, Indonesia. *Forest Ecology and Management* **120**, 157–169.

Kotou M., Havard M., Ouédraogo D., Sangaré M., Toillier A., Thombiano T. and Vodouhe D.S. (2016). Facteurs d'adoption des innovations d'intégration agriculture-élevage: cas du Mucuna pruriens en zone cotonnière ouest de Burkina Faso. *Tropicultura* **34**, 424–439.

Koutika S.L., Hauser S. and Henrot J. (2001). Soil organic matter assessment in natural regrowth, Pueraria phaseoloides and Mucuna pruriens fallow. *Soil Biology Biochemistry* **33**, 1095–1101.

Mehlich M. (1984). Mehlich 3 soil test extractant: a modification of the Mehlich 2 extractant. *Communications in Soil Science and Plant Analysis* **15**, 1409–1416.

Motomizu S., Wakimoto P. and Toei K. (1983). Spectrophotometric determination of phosphate in river waters with molybdate and malachite green. *Analyst (London)* **108**, 361–367.

Norgrove L., Nkem J.N. and Hauser S. (2003). Separating the agronomic effects of burning and biomass removal in a typical slash and burn rotation system in the humid tropics. *Biological Agriculture & Horticulture* **21**, 367–381.

Tandzi L.N., Ngonkeu E.M., Nartey E., Yeboah M., Ngeve J., Mafouasson H.A., Nso Ngang A., Bassi O. and Gracen V. (2015). Farmers' adoption of improved maize varieties in the humid forest area of Cameroon. *International Journal of Scientific Engineering and Applied Science* **1**, 17–28.

Tian G., Hauser S., Koutika L.S., Ishida F. and Chianu J.N. (2001). Pueraria phaseoloides cover cropping for the maintenance and improvement of soil fertility. SSSA Special Publication no. 58, Sustaining Soil Fertility in West Africa. pp. 137–155.

Tian G., Kolawole G.O., Ishida F. and Carsky R.J. (2000). On-farm study of pueraria cover crop-fallow system in the derived savanna of West Africa. In Carsky R.J., Eteka A.C., Keatinge J.D.H. and Manyong V.M. (eds), Cover Crops for Natural Resource Management in West Africa. Proceedings of a workshop organized by IITA and CIEPCA, Cotonou, Republic of Benin, October 26–29 1999. pp. 185–193.

Vine H. (1953). Experiments on the maintenance of soil fertility at Ibadan, Nigeria, 1922-33. *Empire Journal of Experimental Agriculture* **21**, 65–85.

Ward J.H. Jr. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association* **58**, 236–244.

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