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LONG-TERM YIELD SUSTAINABILITY AND FINANCIAL RETURNS FROM GRAIN LEGUME–MAIZE INTERCROPS ON A SANDY SOIL IN SUBHUMID NORTH CENTRAL ZIMBABWE

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SUMMARY

To measure the yield and financial returns from five grain legume–maize intercrop combinations over 12 years of cropping, a field experiment was conducted on a loamy sand soil in the subhumid unimodal rainfall environment of Domboshava in north-central Zimbabwe. Inputs and management followed smallholder practice, including partial grazing of crop residues and a zero mineral fertilizer treatment. The intercropped legumes grew moderately well most years. Cowpea averaged the highest grain yield (0.244 t ha^{-1}) and haulm yield (1.54 t ha^{-1}) over the 12 years, followed by pigeonpea and sugar bean. Intercropped pigeonpea yield was the least variable of the legumes over the years. Maize grain yield was highly variable across years with or without fertilizer and was reduced in years of low (533 mm) and high (1313 mm) rainfall. The pigeonpea–maize intercrop grown without fertilizer produced 0.11 t ha^{-1} (6.25 %) more maize grain yield per year than sole crop maize, in addition to pigeonpea grain and haulms. Intercropped cowpea (which yielded more than double the above-ground non-grain biomass of pigeonpea) had less effect on maize grain yield. There was no trend to greater benefits from the legumes on maize yield after more years of intercropping. Net present values of annual margins accumulated over the 12 years for sole maize with fertilizer (US\$1719 ha^{-1}) and without fertilizer (US\$935 ha^{-1}) were higher than the fertilized and unfertilized intercropping options (US\$1017 and US\$745 ha^{-1}). Pigeonpea or cowpea–unfertilized maize generated more financial returns than the other intercrops, but the low yields and high labour costs for the legumes made the intercrops financially unattractive. We conclude that regularly intercropped pigeonpea or cowpea can to a small extent help to maintain maize yield when maize is grown without mineral fertilizer on sandy soils in sub humid zones of Zimbabwe, and simultaneously provide some nutritious food, but that financial considerations will encourage smallholder farmers to persist with growing low input sole crop maize.

INTRODUCTION

Interest in the role of annual legumes in the smallholder cropping systems based on maize (*Zea mays*) in southern Africa has increased during the last 15 years as efforts to develop and test sustainable soil fertility improvement options for these systems have expanded (Kumwenda *et al.*, 1996; Snapp *et al.*, 1998; Waddington *et al.*, 2004). Dual-purpose grain legumes, such as groundnut (*Arachis hypogaea*), cowpea (*Vigna unguiculata*) and pigeonpea (*Cajanus cajan*), are available for human food and for the improvement of soil fertility. These legumes derive a large proportion of their N needs from biological

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N-fixation, often have a relatively low N harvest index, and produce a substantial amount of both grain and biomass, making them attractive to smallholder farmers (Giller, 2001; Sanginga *et al.*, 2001).

The intercropping of grain legumes with maize is a widespread traditional smallholder farming practice in many subhumid and some semiarid parts of southern Africa, including in Zimbabwe (Mafongoya *et al.*, 2003; Natarajan and Shumba, 1990). Legume–maize intercropping enables farmers to produce nutritious foods from the legumes, while maintaining production of the maize starch-staple each year. However, compared with sole crops in rotation, intercropped grain legumes have to be planted at low legume plant population densities, and so produce small amounts of dry matter per ha, fix less N per ha and generally leave little N in the soil (Giller, 2001; Mafongoya *et al.*, 2003). This means that there is less expectation of a significant contribution to soil fertility or of a subsequent improvement in maize yields with the intercrop. While there is often a large increase in maize yield in rotation where maize follows a sole crop grain legume, when intercropped the N and organic matter inputs from grain legumes, including soyabean (*Glycine max*) and groundnut, and the benefits to the grain yield of subsequent maize crops are reported to be much smaller in many smallholder farming situations (Bogale *et al.*, 2004; Giller, 2001).

On the widespread nutrient-depleted granitic sandy soils in Zimbabwe, there are few and very variable reports of N inputs and maize yield benefits from annual grain legume–maize intercrops in the short term, including the cowpea–maize intercrop commonly used by smallholder farmers (Natarajan and Shumba, 1990). Reported benefits depend greatly on the rainfall, soil type, fertilizer and pesticide inputs, and management given. Jeranyama *et al.* (2000) measured an 8–27 % increase in unfertilized maize grain yields following maize intercropped with cowpea or sunnhemp (*Crotalaria juncea*) under simulated smallholder management and inputs on a loamy sand soil at Domboshava, near Harare. They calculated that the intercropped legume reduced the N fertilizer needs of a subsequent maize crop by 36 kg N ha^{-1}. With higher inputs and management, good benefits are still possible. Mupangwa *et al.* (2003) conducted cowpea–maize intercrop experiments on smallholder farms with a high proportion of legume (1:1 ratio land area), the application of lime and P fertilizer for the legume, and rhizobium inoculation of cowpea. They showed that in these more optimal conditions maize grain yield after a cowpea–maize intercrop can be doubled (from 2.3 to 4.6 t ha^{-1}) in subhumid zones and more than doubled (from 0.7 to 1.7 t ha^{-1}) in semiarid zones. These large increases in maize yield were similar to those following a sole crop of velvet bean (*Mucuna pruriens*) green manure, although the amount of N added to the soil was less with the cowpea intercrop than the sole crop of velvet bean. In contrast, with management and inputs far more representative of smallholder farmers, Shumba *et al.* (1990) reported that cowpea intercropping can reduce maize grain yields in dry years on sandy soils in Zimbabwe, when excessive cowpea haulm growth can exhaust water supplies for intercropped maize plants before maturity.

As far as we are aware, there are no longer-term studies of the effect of grain legume–maize intercrops on crop productivity and its sustainability in Zimbabwe. In this paper we report the results of a field experiment with five grain legume–maize intercrop combinations with and without NPK fertilizer applied to maize, conducted under simulated smallholder farm management and inputs on a deep loamy sand soil close to Harare over 12 years. The experiment was designed to assess the longer-term effects of grain legume–maize intercrop combinations on yield trends for maize and the legumes, and their combined financial values over the 12 years.

MATERIALS AND METHODS

The experiment was planted at the AGRITEX (now AREX) Training Centre farm, Domboshava (Natural Region II, 17°35′S, 31°10′E; 1530 m asl; mean season rainfall 880 mm) near Harare, Zimbabwe, for 12 rainfed cropping seasons (1993/94 to 2005/06). The area has a unimodal rainfall pattern with precipitation from November to March, followed by a seven-month generally cool dry season. The site originally supported a dry Miombo woodland that was subsequently cropped for several decades. The field selected was in a natural grass fallow (dominated by *Hyperthelia dissoluta, Sporobolus pyramidalis, Cynodon dactylon, Dactyloctenium aegyptium, Desmodium tortuosum, Richardia scabra, Bidens pilosa* and *Tagetes minuta*) for four years just before the experiment began. The soil was a deep, moderately fertile Haplic Lixisol (Typic Kandiustalf) derived from granite, with a loamy sand texture.

Soil at the Domboshava site was sampled from 5–20 cm soil depth just before the start of the experiment in November 1993, about two months after an initial mouldboard ploughing of fallow land, and again in October 2004. The soil in 1993 had a pH of 4.5 (in 0.01M $CaCl_2$), 0.43 % organic C (Walkley-Black), mineralizable N (KCl extraction) of 24 $\mu g\,g^{-1}$, 42 $\mu g\,g^{-1}$ P (Bray1), 32 $\mu g\,g^{-1}$ K, 12.5 $\mu g\,g^{-1}$ Mg and a cation exchange capacity of 5.17 me per 100g soil. There were indications of a decline in general soil fertility over the 12 years of the experiment, with soil C falling to around 0.32 %, mineralizable N to 11 $\mu g\,g^{-1}$ (in plots with NPK fertilizer) and 5 $\mu g\,g^{-1}$ without fertilizer, and to around 35 $\mu g\,g^{-1}$ P (with and without fertilizer). Soil pH was not affected.

A factorial combination of row-intercrop plots at two NPK fertilizer rates was arranged in a randomized complete block design with two replicates. We intercropped groundnut (initially ‘Spanish’ type collected from local smallholder farmers, later ‘Egret’ or ‘Falcon’ variety), sugar bean (*Phaseolus vulgaris*) (collected from local farmers), medium maturity (ca. 140 days) pigeonpea ‘Ex Chitedze’ Malawi, an indeterminate habit cowpea (from local farmers, or ‘Zimbabwe Red’) and bambara nut (*Vigna subterranea*) (from local farmers) with SC501 (SC513 in later years) hybrid maize. Crops were planted on the same plots for 12 years. Maize was planted in rows 90 cm apart with two plants each 50 cm along the crop row. Legumes were planted in double rows 50 cm apart, where the legume replaced every third row of maize. Thus, approximately two-thirds of the plot area was planted to maize and one-third to the legume. Legume plant spacing along the crop row was 10 cm for sugar bean and cowpea, 20 cm for groundnut and bambara nut, and 40 cm for pigeonpea. In every second year, the maize rows were offset by one maize row to allow the maize to take advantage of any N input from the legumes grown on that soil the previous year. The plot size was 45.9 m^2, with the equivalent of eight maize rows per plot. Maize was also planted as a sole crop. The plant population density of the sole crop maize was approximately 44 000 plants ha^{-1} and the intercropped maize plant density was approximately 29 000 plants ha^{-1}; each was achieved by over-seeding and then thinning.

Maize and legume seeds were planted into moist soil on the same date shortly after the rains had begun, usually between 22 November and 10 December. One set of plots received no mineral fertilizer throughout the 12 years. The other set received NPK fertilizer each year, with the type of fertilizer, its rate, timing and method of application closely following smallholder farming practice in neighbouring communal areas. A basal dressing of 22 kg N, 17 kg P and 16 kg K ha^{-1} was point-placed on the soil surface about 5 cm from each maize plant, 7–14 days after crop emergence each year. The maize crop was top-dressed with 70 kg N ha^{-1} from ammonium nitrate, point-placed on the soil surface about 5 cm from each maize plant 5–6 weeks after emergence when the crop was 60 cm tall. Each year, the experiment was clean-weeded two or three times using hand hoes. No rhizobium inoculant or fertilizer was used on the legumes, reflecting recent smallholder farmer practice. Chlorpyrifos insecticide was sprayed on the legumes in several years to control caterpillars. Endosulfan granules were applied to maize to control stalk borer. Daily rainfall was measured from a rain gauge adjacent to the experiment. Seasonal rainfall ranged from 1339 mm in 1996/97 to 401 mm in 2001/02 (Figure 1), one of the worst drought years on record in the area, when only 36 mm of rainfall fell from 16 January to mid April. This coincided with the period from maize tasseling to the grain-filling phase, and reduced maize grain yields to around 0.1 t ha^{-1} that year.

Maize and legume grains were removed from the plots during the March–May harvest period each year. All legume and maize crop residues were left on the soil surface and partly grazed by cattle during each dry season following common smallholder farm practice in the area. Those crop residues remaining after grazing (around 40 % of the total) were incorporated into the soil during land preparation with a disc plough late in the dry season (October/November). Legume grain yields and non-grain haulm biomass were measured each year from multiple harvests designed to coincide with the maturity period of the legumes. Maize grain yield (at 12.5 % moisture) and maize stover (air dry mass) were measured after physiological maturity each year during April and May. However, severe food shortages in surrounding communities during 2001/02 precipitated the theft of most maize grain from the experiment in April 2002. Unfortunately, this meant that maize and legume grain yields could not be measured that year.

A financial returns analysis of the combined monetary value of the maize and legume grain and by-products (including the approximately 60 % maize stover and legume haulms grazed by cattle) was done each year for each legume–maize combination and for sole maize, with and without fertilizer applied to the maize. The analysis took into account the benefits and costs that a local smallholder farmer would consider, including incremental revenues and production costs such as input costs and local wages. The value of products (grain and stover) (Table 1) and costs of inputs,

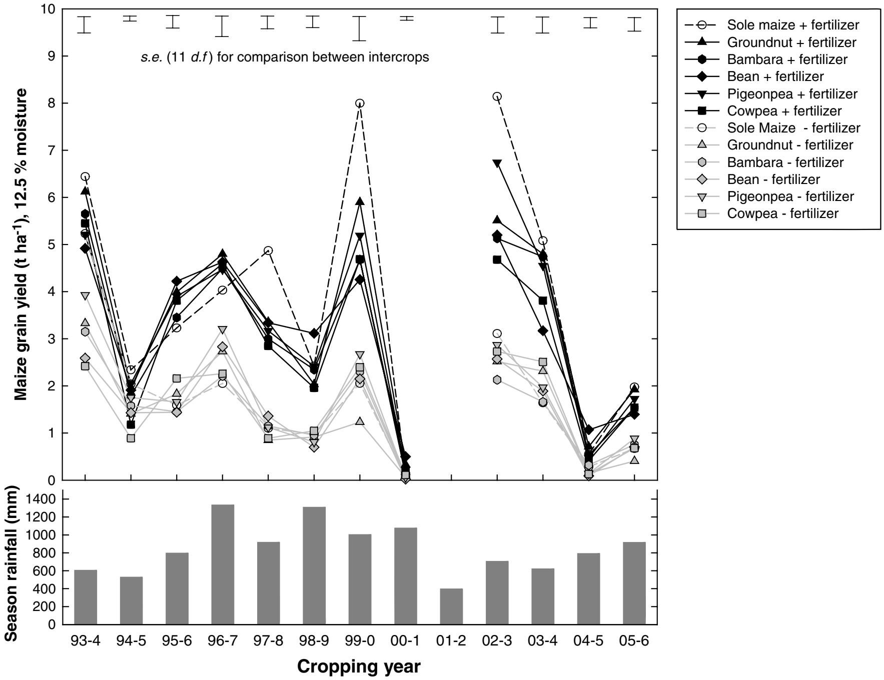

Figure 1. Maize grain yield and season rainfall over 12 years (1993–2006) of intercropping five grain legumes with maize at Domboshava, Zimbabwe.

Table 1. Grain Marketing Board (GMB) price for maize grain, and grain and stover (or haulm) prices for maize and grain legumes at markets in Chinamhora communal area and Mbare Msika, Harare, Zimbabwe, June 2004.

Crop	Grain (US$ kg^{-1})	Stover (US$ kg^{-1})
Maize (GMB price)	0.04	–
Maize (market price)	0.06	0.01
Groundnut	0.21	0.03
Bambara nut	0.35	0.04
Bean	0.24	0.05
Pigeonpea	0.24	0.01
Cowpea	0.18	0.03

including labour (Table 2) were used to calculate the financial returns of each treatment across the 12 years. Prevailing local wage rates (0.20 US$ day^{-1}) and, considering the very limited employment opportunities in the rural areas, a zero opportunity cost of labour, were used to compare the labour use implications of the different treatments. Many input prices for early years of the experiment were not available and it was not possible to estimate them due to hyperinflation in Zimbabwe. The prevailing prices during 2004 and 2005 were used to calculate the revenues and costs in all years. These were converted to their US$ equivalent at Zim$ 17 000 = US$ 1. In the calculation

Table 2. Labour requirement for legume production and harvesting in Chinamhora communal area, Zimbabwe.

	Groundnut	Bambara nut	Bean	Pigeonpea	Cowpea
		Labour days ha^{-1}			
Land preparation	1.5	1.5	1.5	1.5	1.5
Planting	6.0	5.0	5.0	5.0	3.8
Weeding	42.0	35.0	28.0	25.0	17.5
Fertilization	0.1	0.0	0.0	0.0	0.0
Pulling up/cutting	7.0	5.0	3.0	2.0	3.0
Total	56.6	46.5	37.5	33.5	25.8
		Labour days t^{-1} grain output			
Plucking	38	19	0	0	0
Shelling	20	13	3	3	3
Total	58	31	3	3	3

of returns to labour, the opportunity cost of land was estimated as its local rental value (CIMMYT, 1988) which was about 12 US\$ ha^{-1} a^{-1} at the time.

Estimates of labour requirements for legume production and harvesting (Table 2) were obtained from interviews with smallholder farmers in the neighbouring Chinamhora communal area during 2004. Labour required for maize production was 49.5 labour days ha^{-1}, including 1.5 labour days ha^{-1} for land preparation, 4.0 for planting, 0.5 for gap filling, 4.0 for fertilizer application, 31.5 for weeding, 3.0 for cutting stalks and 5.0 labour days ha^{-1} for ear removal. Shelling required 2.5 labour days per t grain output. In Zimbabwe, small amounts of maize grain can be sold in local markets, but larger surpluses have to be sold to the Grain Marketing Board (GMB) at a lower price. Grain and stover prices for maize and the grain legumes were obtained from Chinamhora farmers and Mbare Msika market in Harare during June 2004, and from the GMB in 2004 (Table 1). For each intercrop and fertilizer combination, a net present value (NPV) of the annual margins was computed separately using market prices by summing discounted annual margins (Gittinger, 1984) for the 12-year period. The advantage of NPV as a financial performance indicator is that it is an absolute measure of the present worth of an income stream accruing to individual farmers (Gittinger, 1984). Because prices were assumed to be constant (based on the year 2004/05), discounting was done using a 'real' interest rate. High price distortions and hyperinflation make the actual interest rate for Zimbabwe unrealistic. The interest rate was estimated to be negative 40 % in 2005 (Muñoz, 2007). Since this is highly atypical, and unlikely to prevail, a positive but low interest rate of 5 % was used in the analysis. Discounting was applied at 5 % per year. The discounting rate is the rate at which one unit at a future date is converted to assess its value today. The benefit and cost values for outputs and inputs were discounted to measure their respective current values used to compute the NPVs of each treatment. The internal rate of return (IRR), an alternative financial indicator that does not depend on the discount rate, would have been ideal. However, because the annual margins did not have an initial cash outlay, the IRR could not be computed. Sensitivity analysis (CIMMYT, 1988) was done to see the impact of likely changes in output prices, particularly the lower GMB maize price, on the relative profitability of the treatments. Financial interpretations of intercropping followed guidelines in Anandajayasekeram *et al.* (1990).

RESULTS

Legume yield

Legume growth and yield were variable by species and from year to year. Several of the legumes (sugar bean, cowpea and pigeonpea) grew well in most years, producing up to 0.807 t ha^{-1} grain yield (with cowpea) (Table 3) and up to 3.37 t ha^{-1} non-grain aboveground biomass (again with cowpea). Groundnut produced as little as 0.009 t ha^{-1} grain (Table 3). Low legume yields in 1996/97, 1998/99 and 2000/2001 (Table 3) were due to excessive rainfall (1339, 1313 and 1081 mm, Figure 1), and slight damage by wild pigs. No data were obtained in 2001/2002 because crops in the experiment were destroyed by warthogs, wild pigs and human theft, brought about by widespread hunger after a severe drought (only 401 mm rainfall during maize development). Use of mineral fertilizer on maize had no significant effect on legume grain yield (Table 3) and slightly reduced the legume non-grain above-ground biomass (Table 4). Cowpea gave the highest average yields of 0.24 t ha^{-1} grain (Table 3) and 1.66 t ha^{-1} non-grain above-ground biomass (haulm) over the 12 years ($p < 0.01$) (Table 4) without fertilizer. Sugar bean and pigeonpea were the other intercrop legumes with high grain yield (Table 3), while pigeonpea also produced high haulm biomass (Table 4). Variability for grain yield across the years was highest for bambara nut (coefficient of variation (CV) = 154 %) and lowest for pigeonpea (CV = 71 %) with or without fertilizer on the maize (Table 3).

Maize yield

Over the 12 years, average maize grain yields with fertilizer ranged from as little as 0.14 t ha^{-1} in 2000/01 and 0.55 t ha^{-1} in 2004/05 to well over 6 t ha^{-1} in 1993/94, 1999/2000 and 2002/2003 (Figure 1, Table 3). Low yields of maize grain were often associated with very high rainfall (as in 1998/99 with 1313 mm rainfall during maize development, or in 2000/01 with 1081 mm, Figure 1) when crops became waterlogged and suffered from leaching of N, or with low rainfall (as in 1994/95 with 533 mm or 2001/02 with 401 mm) when crops suffered from serious water deficits. There were indications of less variation (lower CV) with grain yields from intercropped maize than for sole maize (Table 3). With mineral fertilizer on maize, sole maize out-yielded ($p <$ 0.05) maize from all the intercrop treatments in seven out of 12 years, while in other years the yields were similar or lower (Table 3, Figure 1).

Without fertilizer on maize, the intercrop treatments had a clearer and more consistent benefit to maize grain yield. In the first two years of intercropping, sole crop maize out-yielded the intercrops ($p < 0.05$). In all years since then several intercrops produced similar maize yields to sole crop maize (Table 3, Figure 1). The pigeonpea–maize intercrop gave a higher maize grain yield than sole crop maize in seven out of the 12 years ($p < 0.05$) (Table 3, Figure 1). Averaged over the 12 years, the pigeonpea–maize intercrop produced 0.11 t ha^{-1} (6.3 %) of additional maize grain

Table 3. Annual maize and legume grain yields (t ha^{-1}) for sole crop maize and five grain legume–maize intercrops grown with or without mineral fertilizer over 12 years from 1993 to 2006 at Domboshava, Zimbabwe. (Yields could not be measured in the 2001/02 season due to theft of the crop.)

Fertilizer and intercrop combination	Year													
	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/2000	2000/01	2002/03	2003/04	2004/05	2005/06	*s.d.*	Mean	CV
						Maize grain yield with fertilizer									
Sole maize	6.44	2.34	3.23	4.03	4.87	2.42	8.00	0.14	8.14	5.08	0.55	1.98	2.66	3.84	69.3
+ Groundnut	6.12	1.96	3.99	4.80	3.36	2.03	5.90	0.33	5.51	4.80	0.71	1.93	2.03	3.34	60.6
+ Bambara nut	5.65	1.79	3.45	4.49	3.00	2.35	4.68	0.20	5.13	4.74	0.53	1.54	1.85	3.03	61.0
+ Bean	4.92	1.91	4.22	4.63	3.34	3.12	4.26	0.50	5.20	3.17	1.07	1.40	1.59	3.03	52.6
+ Pigeonpea	5.21	2.05	3.90	4.47	3.17	2.42	5.19	0.22	6.74	4.55	0.47	1.73	2.01	3.24	62.2
+ Cowpea	5.45	1.18	3.81	4.59	2.85	1.96	4.69	0.10	4.68	3.81	0.41	1.54	1.84	2.84	64.7
						Maize grain yield without fertilizer									
Sole maize	5.23	2.04	1.59	2.05	1.10	0.97	2.05	0.06	3.11	1.64	0.28	0.67	1.40	1.71	81.9
+ Groundnut	3.33	1.41	1.83	2.73	0.85	0.92	1.23	0.06	2.52	2.31	0.15	0.41	1.07	1.45	73.9
+ Bambara nut	3.15	1.58	1.45	2.21	1.15	0.95	2.30	0.06	2.13	1.66	0.32	0.76	0.89	1.43	62.2
+ Bean	2.59	1.43	1.44	2.83	1.36	0.70	2.15	0.02	2.57	1.89	0.09	0.71	0.96	1.44	66.6
+ Pigeonpea	3.93	1.75	2.66	3.21	1.12	0.81	2.68	0.06	2.87	1.97	0.14	0.89	1.25	1.80	69.7
+ Cowpea	2.42	0.89	2.16	2.26	0.89	1.05	2.40	0.11	2.73	2.51	0.13	0.68	0.98	1.48	66.5
s.e.	0.38	0.13	0.29	0.44	0.32	0.27	0.53	0.07	0.37	0.38	0.18	0.27			
						Legume grain yield with fertilizer									
+ Groundnut	0.052	0.110	0.013	0.009	0.144	0.103	0.106	0.076	0.357	0.120	0.057	0.175	0.09	0.110	84.8
+ Bambara nut	0.061	0.061	0.015	0.020	0.051	0.066	0.044	0.044	0.654	0.028	0.098	0.040	0.18	0.099	168.8
+ Bean	0.373	0.604	0.065	0.011	0.184	0.297	0.351	0.155	0.076	0.338	0.031	0.615	0.21	0.258	81.8
+ Pigeonpea	0.135	0.472	0.059	0.042	0.265	0.132	0.180	0.122	0.251	0.272	0.429	0.085	0.14	0.204	69.8
+ Cowpea	0.319	0.712	0.116	0.002	0.307	0.116	0.094	0.062	0.379	0.081	0.270	0.515	0.21	0.248	86.5
						Legume grain yield without fertilizer									
+ Groundnut	0.050	0.117	0.014	0.014	0.058	0.112	0.212	0.089	0.359	0.229	0.039	0.115	0.10	0.117	88.5
+ Bambara nut	0.078	0.080	0.031	0.010	0.068	0.110	0.085	0.050	0.545	0.037	0.040	0.070	0.14	0.100	137.8
+ Bean	0.287	0.637	0.184	0.020	0.127	0.267	0.205	0.105	0.076	0.283	0.031	0.235	0.17	0.205	82.1
+ Pigeonpea	0.132	0.304	0.095	0.033	0.232	0.118	0.351	0.123	0.109	0.349	0.558	0.130	0.15	0.211	73.4
+ Cowpea	0.419	0.807	0.101	0.021	0.315	0.126	0.099	0.096	0.375	0.070	0.209	0.240	0.22	0.240	92.0
s.e.	0.023	0.041	0.016	0.011	0.027	0.030	0.024	0.008	0.022	0.039	0.027	0.029			

Table 4. Mean maize and legume non-grain aboveground biomass yields with and without mineral fertilizer, over 12 years from 1993 to 2006 at Domboshava, Zimbabwe. (Yields could not be measured in the 2001/02 season due to theft of the crop.)

Fertilizer and intercrop combination	Maize stover yield (t ha^{-1})	Grain legume haulm yield (t ha^{-1})
	With fertilizer	
Sole maize	4.75	–
+ Groundnut	4.35	0.432
+ Bambara nut	4.14	0.486
+ Bean	4.80	0.407
+ Pigeonpea	4.49	0.755
+ Cowpea	4.10	1.412
	Without fertilizer	
Sole maize	2.50	–
+ Groundnut	2.31	0.469
+ Bambara nut	2.48	0.566
+ Bean	2.55	0.424
+ Pigeonpea	2.84	0.711
+ Cowpea	2.66	1.662
s.e.	0.43	0.151

yield per year compared with sole crop maize (Table 3). Maize from the pigeonpea intercrop out-yielded sole maize by over 1.1 t ha^{-1} in 1996/97 and nearly 0.7 t ha^{-1} in 1999/2000 ($p < 0.05$) (Figure 1, Table 3). There was no trend to greater effects after more years of intercropping. All other intercrops yielded less maize grain than with the sole crop (Table 3). Maize stover yields were also highest for the pigeonpea intercrop (Table 4). Cowpea produced very large amounts of non grain biomass in the intercrop (1.53 t ha^{-1} per year averaged over the 12 years, Table 4), but this had a small non significant effect on maize grain yield, even in the later years of the 12-year sequence (Figure 1, Table 3).

Financial return

In nine out of 12 years, the sole maize–fertilizer combination gave the highest yearly NPVs, except in the very wet 1998/99 and 2000/01 seasons and the relatively dry 2004/05 season. The NPV by grain legume–maize intercrop combination, indicating the returns per unit of land under local wage and zero opportunity cost scenarios, and returns to labour, accumulated for the 12 years, are ranked in Table 5. For returns to land, fertilized sole crop maize had the highest NPV under both assumptions of family labour cost. This is explained by the generally high maize yield response to mineral fertilizer and low yield of most legumes. Pigeonpea, sugar bean and cowpea were financially the best legume intercrops (Table 5). Rankings were similar under both labour scenarios.

All the unfertilized legume–maize intercrops had lower NPVs than sole unfertilized maize under both labour cost scenarios (Table 5). This was due to the combination of a negligible yield effect of the legumes on the unfertilized maize in following years (Figure 1) and low yields (of both grain and haulms) of legumes relative to unfertilized

Table 5. Returns to land assuming two labour cost scenarios, and returns to labour (US$ person-day^{-1}) accumulated over 12 years (1994–2006) for legume–maize intercrops at Domboshava, Zimbabwe.

	Returns to land NPV† (5 %) US$ ha^{-1}				Returns to labour NPV (5 %) US$ person-day^{-1}	
Fertilizer and intercrop combination	Local wage	Rank	Zero opportunity cost	Rank		Rank
With fertilizer						
Sole maize	1719	1	1851	1	2.36	1
+ Groundnut	926	5	1055	5	1.32	6
+ Bambara nut	780	7	898	7	1.21	7
+ Bean	962	3	1067	3	1.58	2
+ Pigeonpea	1017	2	1137	2	1.54	3
+ Cowpea	896	6	1056	4	1.04	9
Without fertilizer						
Sole maize	936	4	1046	6	1.54	4
+ Groundnut	457	11	573	11	0.70	12
+ Bambara nut	434	12	540	12	0.70	11
+ Bean	597	10	696	10	1.08	8
+ Pigeonpea	745	8	841	8	1.37	5
+ Cowpea	640	9	779	9	0.86	10

†NPV: Net present value (US$ ha^{-1}).

maize. Without fertilizer, pigeonpea and cowpea intercrops achieved the best returns to land, with groundnut and bambara nut the least (Table 5). Groundnut and bambara nut also had the worst returns to labour. The insensitivity of the analysis to both labour valuations was due to the small difference between the local wage and the assumed opportunity cost. Generally, the opportunity cost of labour is very low when there is no better alternative off-farm use of labour. For many households in rural Zimbabwe that situation is now common. However, pigeonpea, cowpea and bean were favoured by their relatively low labour requirement, while others (groundnut and bambara nut) have a high labour requirement (Table 2), which means they are unattractive at the low yield levels measured in this experiment.

In the sensitivity analysis (Table 6), the NPVs were more responsive to changes in maize prices than changes in legume prices. Sole maize and legume intercrops with fertilizer were more responsive than the unfertilized ones. Imposing the lower GMB price for maize reduced the profitability of all treatments by about 25 %, with the fertilized options more affected than the unfertilized ones. But this did not change the relative profitability of the treatments: sole maize fertilized and unfertilized remained more profitable than the respective legume intercrops. Very large increases (well over 100 %) in the price of legumes would be required to make legume–maize intercrops more profitable than sole maize.

DISCUSSION

The high degree of seasonal variability in maize and legume yield shown in this experiment has been noted often before on sandy soils derived from granite in

Table 6. Sensitivity of net present value (NPV) to changes in output prices (US$ ha^{-1}) for legume–maize intercrop technologies at Domboshava, Zimbabwe.

Fertilizer and intercrop combination	Changes in NPV associated with changes in maize and legume prices							
	GMB maize price (−25 %)		+25 % legume price		+50 % legume price		+25 % maize price	
	NPV (US$)	(%)	NPV(US$)	(%)	NPV (US$)	(%)	NPV(US$)	(%)
				With fertilizer				
Sole maize	1224	−28.7	1718	0.0	1718	0.0	2212	28.7
+ Groundnut	636	−31.3	939	1.5	953	3.0	1214	31.3
+ Bambara nut	517	−33.6	800	2.6	820	5.1	1042	33.6
+ Bean	709	−26.2	1012	5.2	1062	10.4	1214	26.2
+ Pigeonpea	738	−27.4	1053	3.6	1090	7.3	1295	27.4
+ Cowpea	649	−27.5	948	5.9	1001	11.8	1142	27.5
				Without fertilizer				
Sole maize	703	−24.8	935	0.0	935	0.0	1167	24.8
+ Groundnut	329	−27.9	479	4.9	502	9.8	584	27.9
+ Bambara nut	306	−29.2	455	5.0	476	10.0	559	29.2
+ Bean	471	−21.1	643	7.8	689	15.5	723	21.1
+ Pigeonpea	585	−21.3	781	5.0	818	9.9	903	21.3
+ Cowpea	512	−19.9	697	9.0	755	18.0	766	19.9

Zimbabwe where there is also considerable variability in the rainfall patterns within seasons in the subhumid as well as semi-arid zones (e.g. Shamudzarira and Robertson, 2002; Shumba *et al.*, 1992; Vogel, 1993).

Intercrop yield

As expected, groundnut and bambara nut (which rarely intercrop well with maize) and bean (which is very early maturing) all produced relatively little biomass and had the least effect on maize yield. Despite producing large amounts of haulm biomass that was largely incorporated into the soil each year, cowpea with mineral fertilizer on maize often reduced maize yield. The type of cowpea used (an indeterminate spreading type with low grain and N harvest index), was competitive with maize and reduced maize grain yield in some dry years (1994/95 and 2004/05). The competitive effect was often larger than any positive effect of residues and N from cowpea on intercropped maize in following years. This competition has been noted before on sandy soils in Zimbabwe, especially in dry years when excessive cowpea haulm growth can exhaust water supplies for intercropped maize plants before maturity (Shumba *et al.*, 1990).

The relatively good yield performance and stability of the pigeonpea–maize intercrop in this study, despite producing pigeonpea haulm biomass yields (around 0.75 t ha^{-1}) well below those reported for more favourable environments (often 3 t ha^{-1} of leaf litter alone in Malawi (Sakala *et al.*, 2000)), is supported by other work from Zimbabwe and Malawi. In Mangwende, Zimbabwe, with similar conditions to our site, Mapfumo and Mtambanengwe (2004) showed that relatively poorly growing pigeonpea crops can greatly raise maize grain and biomass yields when grown in rotation. They attributed the large improvements after pigeonpea to remobilization and recycling of base nutrients (particularly Mg) and a consequent rise in N-use efficiency by maize, rather than the small input of N fixed by pigeonpea. Additionally, studies in Malawi have established that the growth and development patterns of intercropped maize and later-maturing pigeonpea complement each other. The slow early growth of pigeonpea does not reduce maize yields, while pigeonpea matures on residual moisture after maize is harvested allowing large amounts of N to be added to the soil by fallen leaves (up to 90 kg N ha^{-1}) (Kumwenda *et al.*, 1996; Sakala *et al.*, 2000; Waddington *et al.*, 2004). From our work, we suggest that pigeonpea, which is rarely grown by smallholder farmers in central Zimbabwe at present, is worth testing further with farmers as an intercrop with maize as well as in rotation. It should be relatively easy for smallholder farmers in Zimbabwe to incorporate more pigeonpea and cowpea as intercrops with maize. Farmer assessments of legume suitability in Zimuto, Zimbabwe, for example, rated both these species as highly suited for intercropping with maize on their relatively fertile and productive homestead fields, while farmers considered the relatively shallow and infertile topland fields more suited to bambara nut and groundnut (Kamanga *et al.,* 2003).

Without fertilizer on maize, some of the intercrops produced similar maize yields to sole crop maize, and in the case of the pigeonpea–maize intercrop often exceeded the grain yield of sole crop maize. These maize yield achievements without fertilizer in intercrops may seem unremarkable except that they were obtained at a lower maize plant density (ca. 29 000 plants ha^{-1}), on less land and with partial removal of legume haulms and maize stover through cattle grazing. The grain yield of maize plants on 0.66 ha increased to equal or exceed the yield from 44 000 plants on 1 ha. Without soil fertility inputs from the legumes, we would normally expect maize planted in the row-intercrop arrangement used in this experiment to yield less.

Financial return

Although the yield results showed that several of the grain legume–maize intercrop combinations can help to maintain crop productivity, especially without mineral fertilizer on maize (which is now common for some maize crops grown by Zimbabwean smallholder farmers), the financial analysis showed that intercropping was unattractive compared with growing sole crop maize. Given the small expected yield benefits, combined with the overall low yields achieved in these conditions compared with the relatively high investment costs for legume intercropping, the intercropping of grain legumes with maize appears financially unattractive into the longer term. Only large reductions in the maize price and very large increases in legume price will change this. The overriding profitability of N fertilizer use with maize was clear and has been shown several times recently for these subhumid and semiarid systems in Zimbabwe except in the driest of years (e.g. Shamudzarira and Robertson, 2002; Waddington and Karigwindi, 2001). Intercropped pigeonpea and cowpea gave better returns than the other legumes without fertilizer on maize, but it was still much more profitable to plant sole crop maize without fertilizer. This confirms widespread current smallholder farmer practice in Zimbabwe to plant sole crop maize with increasingly fewer fertilizer and labour inputs rather than to invest in more complex mixed legume–maize systems.

Grain legume–maize sole crop rotational systems have been promoted by agricultural research and extension agencies for smallholders in Zimbabwe for many years in preference to intercrops (Natarajan and Shumba, 1990; Shumba *et al.*, 1990). In those rotational systems, legume yields and legume effects on raising maize yields can often be 2–5 times those of equivalent intercrops (e.g. Waddington and Karigwindi (2001) for groundnut, Mapfumo and Mtambanengwe (2004) for pigeonpea). However, the still relatively low yields of these rotational systems with smallholder farmers and the requirement to forego maize in at least one year out of three mean they too are financially unattractive (e.g. Waddington and Karigwindi, 2001; Waddington *et al.*, 2004).

This all points to the challenge that smallholder farmers face with incorporating more legumes as intercrops (or as rotations) into their maize system. If by doing so at the current prices of labour and the low yields to be expected, they realize a loss compared with sole maize, they will usually opt to continue to grow sole crop maize. It will remain difficult to convince farmers to grow more legumes to get the only slight benefits in crop system sustainability to be expected. However, increasingly few Zimbabwean smallholder farmers are able to apply fertilizer on maize even in the less risk-prone subhumid zones because of the high cost and low availability of N fertilizer. Should access to mineral fertilizer for maize remain difficult in Zimbabwe, our results suggest that the intercropping of pigeonpea or possibly cowpea or sugar bean with maize grown with modest amounts of fertilizer could be an increasingly viable way for smallholder farmers to maintain moderate maize yields and income whilst concurrently harvesting some nutritious food from the legume grains.

CONCLUSION

We found from this study that regularly intercropped pigeonpea or cowpea can help to maintain the yield of maize when grown with inputs and management representative of smallholder farmers on sandy soils in Zimbabwe, including no mineral fertilizer and with partial grazing of crop residues. Additional on-farm research with pigeonpea–maize intercropping is suggested. However, it was not financially attractive for smallholder farmers to intercrop compared with growing low input sole crop maize. This was a result of a combination of very small benefits of the legumes on maize yield, relatively low yields expected from the legumes, high labour costs for some legumes and low monetary values of legume products. The productivity and sustainability benefits for farmers from such systems on sandy soils in central subhumid Zimbabwe will be very modest compared with those expected on more fertile soils in wetter regions. In the Zimbabwean situation, smallholder farmers are likely to persist with growing sole crop maize and with few inputs. Only combinations of major improvements in the price of and demand for legume products, far more productive new varieties of the legumes with qualities preferred by urban and rural consumers, easier harvesting methods and far cheaper maize prices, will improve the viability and adoption of grain legume–maize intercrop systems leading to more sustainable soil fertility management and productivity. Furthermore, this will need support from initiatives to build farmer knowledge and awareness of the soil fertility contributions and subsequent long-term benefits from legumes.

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