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Full Length Research Paper

The sustainability of a groundnut plus maize rotation over 12 years on smallholder farms in the sub-humid zone of Zimbabwe

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An experiment was conducted on four smallholder farms and on-station in the sub-humid zone of northeast Zimbabwe for 12 years to assess how the rotation of groundnut with NPK-fertilized and unfertilized maize affected the productivity and sustainability of this common smallholder cropping system. At the sandy-soil Domboshava station, maize grain yield declined over 12 years of continuous maize cropping, and the rate of decline was larger when fertilizer was used. Maize grain yield was already low (around 0.7 t ha^{-1} without fertilizer) on the smallholder farm fields when the experiment began, and there was little evidence of further decline. A 3-year groundnut plus maize plus maize rotation raised maize grain yield on station both when fertilizer was used on maize and when not, with some benefits persisting into the second year of maize after groundnut. Three cycles of the rotation with fertilizer at Domboshava increased maize yields by 0.21, 2.92 and 2.26 t ha^{-1} in the first year after groundnut. With unfertilized maize, grain yields rose by 2.15, 1.52 and 3.61 t ha^{-1}, which was double or more than double those from continuous maize plots. Accumulated over three rotation cycles (nine years) on station, the rotation gave 3.54 t ha^{-1} (13.2%) more maize grain than continuous maize with fertilizer and 5.33 t ha^{-1} (42.2%) more when fertilizer was not used, as well as almost 1 t ha^{-1} of groundnut grain. On the farms, overall yields of groundnut and maize were much smaller, because soils and management were poorer, and inputs few. Groundnut crops averaged less than 0.13 t ha^{-1} grains. The rotation raised maize grain yield only when no fertilizer was used on maize, where three cycles of the rotation raised maize grain yields by 0.21, 0.38 and 0.32 t ha^{-1}. Accumulated over three rotation cycles, the rotation without fertilizer gave 0.51 t ha^{-1} (15.1%) more maize grain than continuous maize on the farms, and 0.4 t ha^{-1} of groundnut grain. It was concluded that the rotation of groundnut with maize can sustain the productivity of smallholder maize systems in sub-humid northeastern Zimbabwe in moderately fertile station conditions and can contribute on nutrient-depleted smallholder fields even when the crops are grown without fertilizer and with few management practices.

Key words: Groundnut, maize, crop rotation, soil infertility, longer-term experiment, on-farm research, sustainability, sub-humid zone, Zimbabwe.

INTRODUCTION

The rotation of groundnut (*Arachis hypogaea* L.) with maize (*Zea mays* L.) is recognized as an important soil fertility management option for smallholder farmers in sub-humid parts of Zimbabwe (Snapp et al., 1998; Waddington and Karigwindi, 2001; Waddington et al., 2004; Mafongoya et al., 2006). Non-systematic groundnut plus maize rotations are widely practiced by smallholders in northern and central Zimbabwe (Metelerkamp, 1987; Snapp et al., 1998; Waddington and Karigwindi, 2001). These crops are well liked because farmers know how to grow them within their cash and labour limitations to provide several useful food products for home consumption and some income. However, the productivi-

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Table 1. Soil texture and chemical properties of soils sampled during 1992-94 from fields planted with a groundnut + maize rotation at Domboshava research station and on four smallholder farms in northeast Zimbabwe.

Site	Soil texture	pH(in 0.01 M $CaCl_2$)	C(%)	Mineralizable N(ppm)	P (Bray, µg g^{-1})	K(µg g^{-1})	Mg(µg g^{-1})
Domboshava station	Loamy sand	4.5	0.43	24.1	41.9	31.8	12.5
Chinyika farm 1	Loamy sand	4.3	0.52	18.6	1.3	78.0	20.0
Chinyika farm 2	Sandy loam	4.3	0.42	3.7	3.5	60.5	20.0
Chiduku farm 1	Sandy clay loam	4.7	1.35	41.6	0.4	169.0	77.9
Chiduku farm 2	Sandy clay loam	4.3	0.83	31.6	4.8	87.5	12.5

ty of groundnut on smallholder farms remains low due to a wide range of constraints that include the planting of poor quality saved seed, late planting of the crop, low achieved plant population densities, high labour requirements and a range of soil infertility issues (including soil acidity; deficiency of P, Ca and Mg; and lack of use of basal fertilizer) (Natarajan and Zharare, 1994; Chikowo et al., 1999; Waddington and Karigwindi, 2001; Murata et al., 2002; Mupangwa and Tagwira, 2005). Large increases in maize yields following groundnut have been reported several times on research stations in Zimbabwe (Mukurumbira, 1985; Waddington and Karigwindi, 2001) but these can be absent or very small on smallholder farms where groundnut is now grown with no fertilizer and few other inputs (Waddington and Karigwindi, 2001).

Despite the continued popularity of these irregular groundnut plus maize rotations in sub-humid parts of Zimbabwe, little information exists about their contribution to longer term trends in crop productivity or soil fertility over ten or more years, especially on smallholder farms. More generally this is the case also for other soil fertility practices that smallholders use in Zimbabwe and elsewhere in southern Africa (Kumwenda et al., 1996; Giller et al., 1998; Harrington and Grace, 1998). Assessments need to be conducted on smallholder farms over many years with the inputs and management that farmers use. This type of research is perceived to be risky, expensive to implement and slow to generate results, and is rarely done. In an assessment of longer-term arable experiments in Africa, Greenland (1994) and Swift et al. (1994) found many experiments that addressed crop rotations and organic and inorganic soil fertility inputs, but all were researcher-managed on research stations and reflected very poorly the circumstances facing an African farmer (Swift et al., 1994; Scoones, 2001).

In this paper we report results from one study conducted over a longer term on smallholder farms in southern Africa. The work assessed how the rotation of groundnut with fertilized or unfertilized maize over 12 years affected crop yields on smallholder farms and under simulated smallholder management on a research station in the sub-humid zone of northeast Zimbabwe. Yield and profitability results from the initial six years of the experiment were given in Waddington and Karigwindi (2001).

MATERIALS AND METHODS

From 1992 to 2005, CIMMYT conducted a groundnut plus maize rotation experiment on smallholder farms and on station in the sub-humid unimodal rainfall zone (800 - 900 mm in five months, 1,300 - 1,550 masl) of northeastern Zimbabwe. The experiment was first described in Waddington et al. (1998) and Waddington and Karigwindi (2001). It was planted at the AGRITEX Training Centre, Domboshava (17°35'S, 31°10'E; mean season rainfall = 880 mm) near Harare and on four smallholdings in the unimodal sub-humid rainfall zone of northeast Zimbabwe. Two of the farm sites were in Chinyika Resettlement Area (18°10'S, 32°20'E; mean rainfall = 812 mm) and two in Chiduku Communal Area (18°30'S, 31°40'E; mean rainfall 822 mm).

Four experimental sites were chosen with farmers to be representative of the principal topland or mid-slope maize fields that they cultivate. Texture and chemical characteristics of the soils at the trial sites (from samples taken in 1992 - 1994) are presented in Table 1. The soils were predominantly Ustalfs or Lixisols (loamy sands, sandy loams and sandy clay loams) derived from granite. They had a low pH (pH 4.2 - 4.7, in 0.01 M $CaCl_2$), a carbon content of between 0.4 and 0.8%, low cation exchange capacity (CEC) and low amounts of several cations. A major distinction between the Domboshava station and the on-farm sites was soil P (42 µg g^{-1} P (Bray) on station, 0.4-8.9 µg g^{-1} P on-farm). The sites had been cropped for various lengths of time, estimated to be between 12 years (sites in Chinyika) and over 70 years (in Chiduku). Maize had been grown on each field the year before the experiment began.

The experiment was arranged in a randomized complete block design with two replicates at each site. Experimental treatments were:

T1 Continuous maize (year-after-year) - Fertilizer was applied diffusely on the soil surface 4 - 10 cm from each maize plant, according to common farmer practice. NPK compound "D" (275 kg ha^{-1}) was applied 14 days after crop emergence and 70 kg N kg

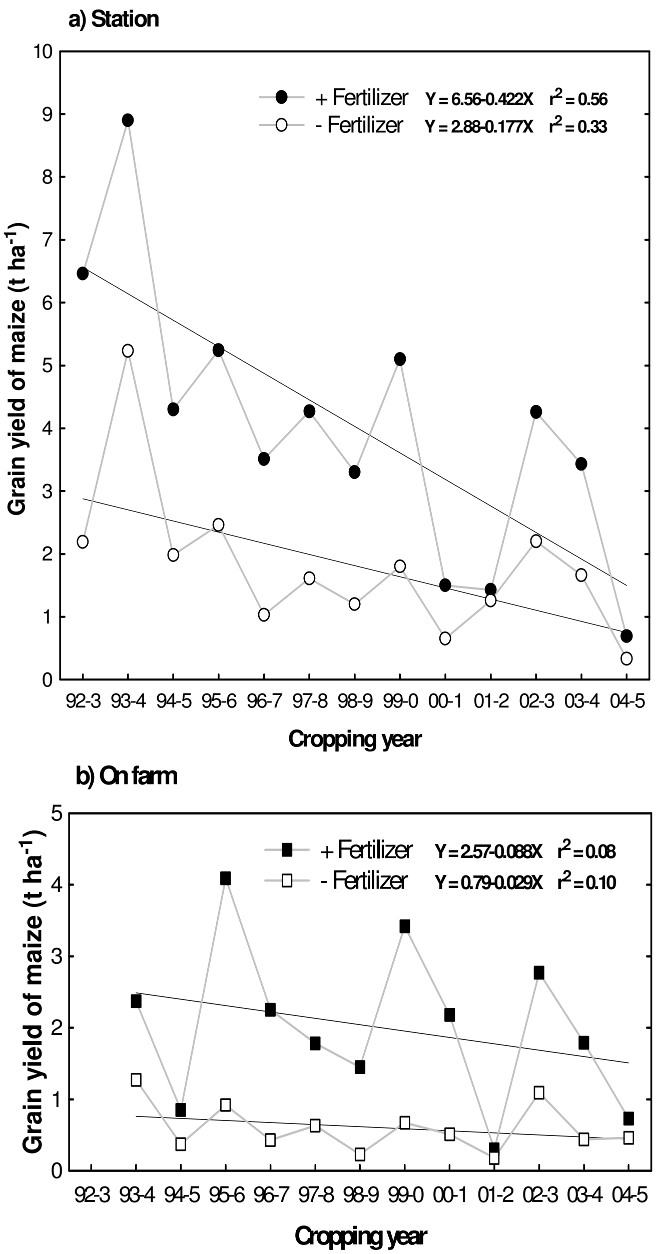

Figure 1. Trends for maize grain yield (t ha^{-1}), with mineral fertilizer (92 kg N, 17 kg P and l6 kg K ha^{-1}) applied each year for 12 years, and without fertilizer, on a) Domboshava research station, and b) averaged over four smallholder farm fields in northeast Zimbabwe, 1992-2005. Straight lines are linear regressions.

ha^{-1} topdress ammonium nitrate fertilizer when the crop was approximately 60 cm tall. This provided 92 kg N, 17 kg P and 16 kg K ha^{-1} per year.

T2 Continuous maize (year-after-year) - No fertilizer applied.

T3 Groundnut + Maize + Maize + Groundnut + Maize + Maize + Groundnut rotation (one crop per year) - Fertilizer on maize as in T1, no fertilizer on groundnut.

T4 Groundnut + Maize + Maize + Groundnut + Maize + Maize + Groundnut rotation (one crop per year) - No fertilizer applied.

Fertilizer rates used in these treatments represented farmer practice when the experiment began and were obtained from detailed agronomic monitoring and surveys with farmers in Mangwende Communal Area (Waddington et al., 1991). The plot size was 10.8 x 10.5 m (113.4 m^2) for both maize and groundnut. Seed of R215 and later SC501 hybrid maize was planted to give a plant population density of 44,440 plants ha^{-1}. Groundnut (usually the small and bushy ‘Spanish’ type, widely used by smallholders) was planted to give a density of approximately 160,000 plants ha^{-1}.

Management, both on-station and on-farm, was representative of farmers’ practices in the area and was jointly undertaken by farmers and researchers. The land was prepared using an ox-drawn mouldboard plough. Groundnut was grown without P fertilizer or gypsum. Weeds were removed at two stages of crop growth using hand-hoes, and cattle and goats were allowed to graze the maize stover and groundnut haulms during the dry season, as happens on farm. Each year, the maize and groundnut grain was harvested and shelled from whole plot areas of 113.4 m^2 and then removed from the field. Maize grain yields were measured at 12.5% moisture content and groundnut grain as sun-dried mass per hectare. Groundnut haulms were collected from the entire plot, weighed and then returned to the field. They are reported as sun-dried mass per hectare. Maize grain yields were used in single-site analyses of variance for each year. The results are presented as year-to-year trends in grain yields.

RESULTS

Continuous maize

There was strong evidence of a large decline in maize grain yield with continuous maize cropping at Domboshava station, but no clear trend was measured on the smallholder farms (Figure 1). At Domboshava, the grain yield decline over the period 1992 - 1993 to 2004 - 2005 was estimated from linear regressions to be 0.42 t ha^{-1} per year with NPK fertilizer and 0.18 t ha^{-1} per year without fertilizer (Figure 1a).

On-farm, maize grain yields without fertilizer averaged 0.6 t ha^{-1} and were below 0.45 t ha^{-1} in six out of 12 years (Figure 1b). Linear regression showed a slight but non significant trend to lower grain yield. With fertilizer, the on-farm yields were highly variable (Figure 1b). On farm maize grain yield responses to N fertilizer (calculated for 92 kg N ha^{-1} applied compared with zero N applied) were low (between 5 and 16 kg grain kg N^{-1}) in eight of the 12 years.

Groundnut plus maize rotation

Grain yield is reported for groundnut and for NPK-fertilized and unfertilized maize following groundnut in three complete cycles (nine years) of the groundnut plus maize plus maize rotation at Domboshava station (Figure 2) and on the four smallholder farms (Figure 3).

Domboshava station: At Domboshava, the rotated groundnut crops produced from 0.152 to 0.369 t ha^{-1} of shelled grain (Figure 2) and 0.60 to 1.45 ha^{-1} of aboveground haulms. Large effects (p < 0.01) of groundnut on maize yield with fertilizer were measured for the second and third cycles of the rotation at Dombo-

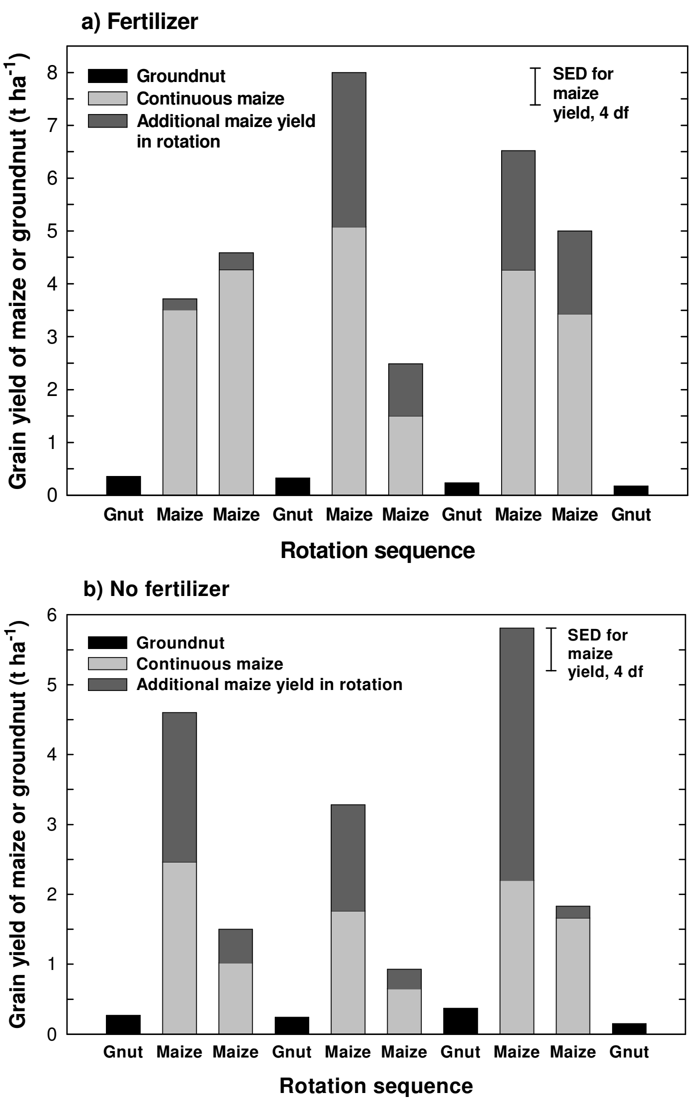

Figure 2. Grain yield of groundnut and maize (t ha^{-1}) in three cycles of a groundnut + maize + maize rotation, a) with 92 kg N, 17 kg P and 16 kg K ha^{-1} fertilizer on each maize crop, or b) without fertilizer, at Domboshava station, Harare, Zimbabwe, 1994-2005.

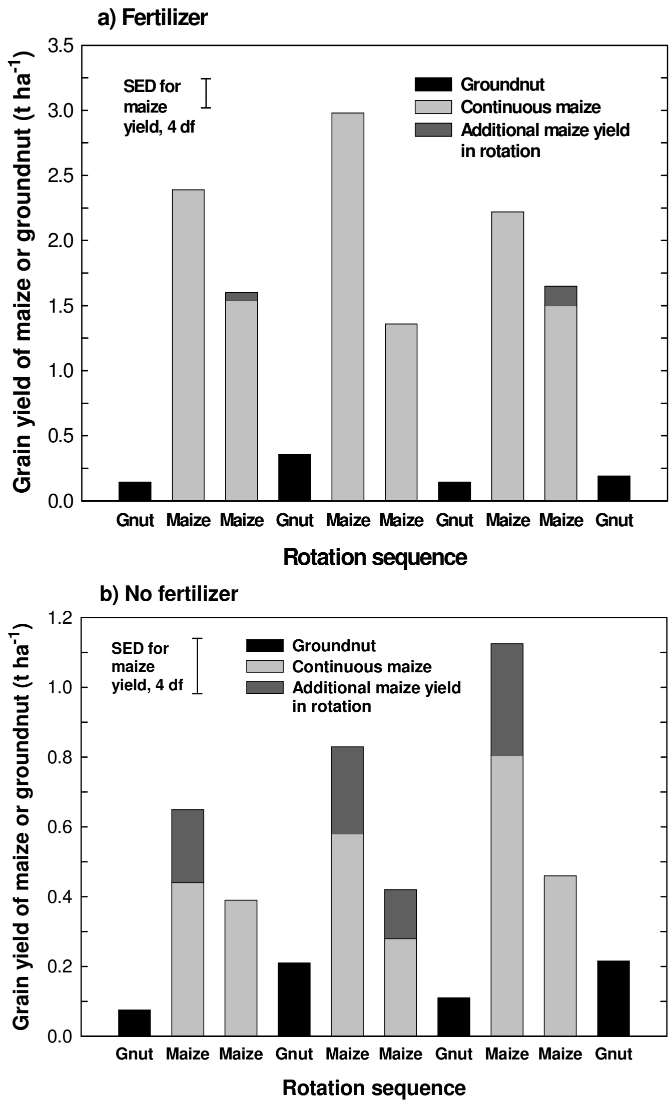

Figure 3. Grain yield of groundnut and maize (t ha^{-1}) in three cycles of a groundnut + maize + maize rotation, a) with 92 kg N, 17 kg P and 16 kg K ha^{-1} fertilizer on each maize crop, or b) Without fertilizer, averaged over four smallholder farms in Chinyika and Chiduku, northeastern Zimbabwe, 1995-2005.

shava (Figure 2a). In the first rotation cycle (1994 - 1997), the rotation with groundnut raised the grain yield of the following maize crop (1995 - 1996) by 0.21 t ha^{-1} (6%) and by 0.32 t ha^{-1} (7.5%) in the second year of maize following groundnut (1996 - 1997) (Figure 2a). In the second cycle (1998 - 2001), maize grain yields with the groundnut rotation rose by 2.92 t ha^{-1} or 57.5% in the first year after groundnut (reaching 8 t ha^{-1}) and 0.99 t ha^{-1} or 66% in the second (Figure 2a). In the third cycle (2002-2005), maize grain yield increased by a further 2.26 t ha^{-1} (53.1%) for the first year of maize after groundnut and 1.57 t ha^{-1} (45.8%) for the second year of maize (Figure 2a). Accumulated over three rotation cycles (nine years) of cropping, the rotation gave 3.54 t ha^{-1} more maize grain than continuous maize and almost 1 t ha^{-1} of groundnut grain (Table 2).

Even larger rotation effects ($p < 0.01$) were found at Domboshava when no fertilizer was given to maize. In the first rotation cycle (1994 - 1997), the rotation with groundnut almost doubled the grain yield of the following maize crop (1995 - 1996) from 2.46 to 4.61 t ha^{-1}, an increase of 2.15 t ha^{-1} (87%) (Figure 2b). Effects of groundnut on maize persisted in the second year of maize following groundnut (1996 - 1997) where maize grain yield increased by 0.47 t ha^{-1} (46%) (Figure 2b). In the second cycle (1998 - 2001), maize grain yields again increased in the groundnut rotation (by 1.52 t ha^{-1} or 86%

Table 2. Summary of maize and groundnut grain yield (t ha^{-1}) from a groundnut + maize + maize rotation relative to continuous maize, accumulated over three cycles (nine years) of the rotation at Domboshava station and on four smallholder farms in sub-humid northeast Zimbabwe, 1993-2005.

	Domboshava station (t ha^{-1})	Smallholder farms (t ha^{-1})
Continuous maize with fertilizer	26.78	13.74
Maize in rotation with fertilizer on maize (Groundnut)	30.32 (0.918)	12.20 (0.645)
Continuous maize without fertilizer	12.62	3.37
Maize in rotation without fertilizer on maize (Groundnut)	17.95 (0.880)	3.88 (0.395)

in the first year after groundnut, and 0.28 t ha^{-1} or 43% in the second (Figure 2b). In the third cycle (2002 - 2005), there was a very large further increase of 3.61 t ha^{-1} (164 %) of maize grain for the first year of maize after groundnut and 0.17 t ha^{-1} (10.2%) for the second year of maize (Figure 2b). This represented an average maize grain yield increase of 84.1% (from 1.63 t to 2.99 t ha^{-1}) during each year of unfertilized maize cropping in the rotation over the years, with indications of a rising trend. 5.33 t ha^{-1} of additional maize grain was obtained with the rotation than with continuous maize in the three cycles (nine years) of the rotation, plus 0.88 t ha^{-1} of groundnut grain (Table 2).

Smallholder farms: The growth and grain yield of groundnut was less on farm (Figure 3). There the first cycle of groundnut in rotation produced only between 0.025 and 0.11 t ha^{-1} of shelled grain and between 0.063 and 0.58 t ha^{-1} of aboveground haulms. In the second cycle of the rotation on farm, a better crop of groundnut was achieved, producing an average of 0.21 t ha^{-1} of shelled grain and 0.38 t ha^{-1} of aboveground haulms. In the third cycle, groundnut grain yields averaged 0.13 t ha^{-1} (Figure 3). The productivity of maize was also much less on farm (Figure 3), with an average grain yield of 0.6t ha^{-1} for continuous unfertilized maize.

With fertilizer on maize, groundnut in rotation had very little effect on maize grain yield (Figure 3a). The rotation did not raise the yield of maize in the first year of maize after groundnut for any of the three cycles of the rotation. Very small improvements of 0.06 and 0.15 t ha^{-1} were seen for the second year of maize in the first and third cycles of the rotation (Figure 3a). Accumulated over all three cycles of the rotation, continuous maize gave more maize yield than maize in the rotation (Table 2).

On farm without fertilizer, significant effects ($p < 0.05$) of the rotation on maize were measured. The first cycle of the rotation (1995 - 1999, depending on site) raised maize grain yields in the first year after groundnut at all sites by an average of 48%. However, overall maize yield was 0.65 t ha^{-1} and this increase was only 0.21 t ha^{-1} of maize grain (Figure 3b). The rotation did not improve the yield of maize in the second year. In the second rotation cycle (1998 - 2002, depending on site), maize grain yields were raised both years after groundnut, by an aggregate 0.39 t ha^{-1} or 45% (0.25 t ha^{-1} in year 1 and 0.14 t ha^{-1} in year 2 (Figure 3b). In the third cycle of the rotation (2001 - 2005, depending on site), maize grain yield rose by 40% (0.32 t ha^{-1}) in the first maize crop after groundnut, with no effect on the second (Figure 3b). The average maize grain yield increase during each year of maize cropping in the rotation over the years on farm without use of fertilizer was 31.1% (with yields raised from 0.493 to 0.646 t ha^{-1}). Accumulated over the three cycles (nine years) of the rotation, farmers got an extra 0.51 t ha^{-1} of maize grain from the rotation compared with continuous maize, plus almost 0.4 t ha^{-1} of groundnut grain (Table 2).

DISCUSSION

Continuous maize

In this experiment we measured a considerable decline in grain yield when maize was continuously cropped for 12 years on the relatively fertile station especially when NPK fertilizer was used, but not on the smallholder farms. The on-farm maize yields with fertilizer were highly variable but did not show a declining trend, while without fertilizer there was little evidence of a fall in the already very low (0.6 - 0.7 t ha^{-1}) on farm maize grain yield over the 12 years of the experiment. Smallholder farm maize grain yields in northern sub-humid zones of Zimbabwe have been low for several decades because the predominantly granitic sandy soils in many smallholder fields are inherently infertile and have been further depleted of nutrients through cropping with insufficient fertilizer and inadequate fertility management (Kumwenda et al., 1996; Snapp et al., 1998; Mapfumo and Mtambanengwe, 1999; Mushayi et al., 1999). While these yields are probably declining further now on small farms because even less mineral fertilizer is in use, our experiment suggests that grain yields from continuously cropped maize should be maintainable for several decades without a complete collapse. Although fertilizer was able to maintain yield on farm over the time scale of this experiment, the achieved N use efficiencies of the fertilizer were low (5 - 20 kg grain kg N^{-1} applied), and were similar to those found in another small farm study in sub-humid Zimbabwe by Mushayi et al. (1999). High rainfall (1313 mm, 1998-99) and low rainfall (533 mm, 1994-95; 401 mm, 2001-02) was experienced during the experiment and these extremes of rainfall contribute to low N use efficiencies for maize on granitic sandy soils in the sub-humid areas (Mushayi et al., 1999). The use of smaller doses (e.g. 9-20 kg ha^{-1}) of N fertilizer with maize has been shown to give higher use efficiencies (18 - 31 kg grain kg N^{-1}) in semi-arid zones of Zimbabwe (Ncube et al., 2007). A similar approach may be applicable in wetter areas to raise N use efficiencies and maintain some N use on small farms.

Groundnut rotation

The findings here from three cycles of a groundnut plus maize plus maize rotation in sub-humid zones of Zimbabwe extend those initially reported by Waddington and Karigwindi (2001). The three cycles provide evidence for the substantial improvement in the productivity and sustainability of maize through the incorporation of a smallholder-farmer-managed rotation with groundnut. There were very clear large benefits from the rotation on Domboshava station both with and without fertilizer on maize. The additive benefits of the rotation and fertilizer on-station brought maize grain yields of up to 8 t ha^{-1}. These were achieved under simulated smallholder farm management and on a granitic sandy soil representative of many smallholder areas. The approximate doubling of maize grain yield at Domboshava after groundnut was similar to that reported by Mukurumbira (1985) at the nearby Marondera research station. The major difference from conditions on smallholder farms was greater soil fertility (Table 1).

Although the benefits from the rotation on farm were much smaller, unfertilized maize production in rotation still rose by about 15% compared with continuous maize cropping, and some groundnut was produced as a bonus. These yield benefits will be important for a smallholder farmer faced with the increasingly common reality in Zimbabwe of being unable to apply mineral fertilizer to maize. Additionally, the evidence that benefits were increasing with the second and third cycles of the rotation has important positive implications for the longer term sustainability of the groundnut plus maize rotation on smallholder fields. However, the groundnut rotation made no further contribution to maize yield beyond those from applying fertilizer to maize on the farms. This is unfortunate since farmers would look to get at least a partial additive benefit from both sources of N. In earlier years with the same experiment, Jeranyama et al. (2007) showed that the groundnut rotation had no effect on the use efficiency of N fertilizer applied to maize on the farms, although it improved N use on the station.

The productivity of the rotation was very sensitive to the generally poor performance of the groundnut crop, which is difficult to grow well on many smallholder fields. Several soil fertility, weather, input and management factors contribute to this in Zimbabwe as described in the introduction and discussed further by Chikowo et al. (1999), Waddington and Karigwindi (2001) and Murata et al. (2002). Additionally, with such low groundnut and maize yields expected on smallholder farms and prevailing low prices for groundnut, the financial viability of the rotation is questionable. Reporting profitability results from the initial six years of the present study, Waddington and Karigwindi (2001) found the rotation on farm was financially unattractive when the large amount of labour for the groundnut component of the rotation was costed at rural wage rates. They concluded that it was more profitable to grow continuous maize, especially with mineral fertilizer, than to rotate. We decided not to update the financial analysis because price volatility, price controls, hyperinflation and interest rate distortions in Zimbabwe during the 2000s complicate and reduce the reliability and value of such an analysis. However, there appears to have been deterioration in smallholder crop production economics over this period and a decline in mineral fertilizer use on maize. Increasing difficulties in applying adequate NPK fertilizer to maize in Zimbabwe may help local farmers to see more value in the rotation of groundnut with maize as a partial replacement for N fertilizer on maize. We suggest the challenge for a smallholder farmer in northern Zimbabwe remains how to achieve the modest sustainability benefits that we have demonstrated here from the groundnut plus maize rotation in ways that are socio-economically attractive.

Conclusion

Low grain yields from continuously cropped unfertilized maize are likely to be sustainable over several decades on smallholder farms with granitic sandy soils in sub-humid parts of Zimbabwe. These farms will maintain higher yielding (but more variable) maize production if it is grown with modest inputs of mineral fertilizer. Substantial improvements beyond this are possible when a groundnut plus maize rotation is practiced on relatively fertile soils. Even with the nutrient-depleted conditions commonly found on smallholder fields and farmers' current practices and inputs, a groundnut plus maize rotation can make a significant contribution to the productivity and sustainability of maize cropping on farm in sub-humid parts of Zimbabwe. This will be especially important for the many small farmers in Zimbabwe that can access only small amounts of mineral fertilizer for their maize. In addition, the rotation will provide some groundnut grain, which has a high value for household food and for sale.

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