PRODUCTIVITY AND PROFITABILITY OF MAIZE + GROUNDNUT ROTATIONS COMPARED WITH CONTINUOUS MAIZE ON SMALLHOLDER FARMS IN ZIMBABWE

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SUMMARY

Experiments to assess the yield and economic performance of a maize-groundnut rotation compared with continuous maize (both when inorganic fertilizer was applied to maize and when not), were conducted under management by smallholder farmers in Zimbabwe over six years. The experiment was planted on-station near Harare and at six smallholder sites in northeast Zimbabwe, predominantly on sandy soils. Fertilizer rates and practices were those used by farmers, as described in surveys. On-farm grain yields from continuous maize without fertilizer were generally in the range 0.5–0.8 t ha\(^{-1}\) over five years. Maize yield responses to inorganic fertilizer on smallholder farms were highly variable, but moderate (up to 29 kg grain per kg N) with adequate rainfall. With no inorganic fertilizer applied to maize, the on-station groundnut crop (producing 0.260–0.355 t ha\(^{-1}\) shelled grain) almost doubled the grain yield of the following maize crop (in 1995–96), increasing output from 2.46 t ha\(^{-1}\) to 4.61 t ha\(^{-1}\).

Where inorganic fertilizer was applied to maize, the rotation produced even more additional maize grain (an increase of 2.93 t ha\(^{-1}\)). Up to 0.50 t ha\(^{-1}\) extra grain was obtained in the second year of maize following groundnut (1996–97). With inorganic fertilizer, groundnut improved the grain yield of following maize crops at only two of five on-farm sites. Without fertilizer, the groundnut rotation increased maize grain yields at five on-farm sites by an average of only 0.28 t ha\(^{-1}\). For the on-station groundnut and two subsequent years with maize, discounted net benefits (DNBs) over cash costs (seed and fertilizer) were greater for the rotation than for continuous maize, irrespective of whether or not inorganic fertilizer was applied. When labour costs were added, continuous maize plus fertilizer showed better returns than did the rotation, while the returns for the rotation and continuous maize without fertilizer were almost the same. On-farm the rotation was far less profitable. At only two sites, DNBs over cash costs were higher for the rotation whereas DNBs over all costs (including labour valued at a local casual-worker wage) were always negative or close to zero. At three sites, it was far more profitable to grow continuous maize, especially with fertilizer. These findings of low groundnut yield, marginal to zero profitability, and high labour cost of groundnut-maize rotations, support and explain the general trend by smallholder farmers to reduce groundnut area in Zimbabwe.

INTRODUCTION

Groundnut (\textit{Arachis hypogaea}) can fix large amounts of N (Williams, 1979; Giller \textit{et al.}, 1994; 1997) and is widely accepted by local smallholder farmers as an important source of protein. It has been considered, therefore, one of the most useful grain legumes to help maintain the soil fertility and productivity of
smallholder maize-based cropping systems in southern Africa. For many years the rotation of maize (\textit{Zea mays}) with groundnut has been the most common legume-cereal crop sequence on smallholder farms in sub-humid parts of Zimbabwe (Shumba, 1983; Metelerkamp, 1987). Also, groundnut is an important cash crop in semi-arid areas (Scoones, 1996). However, both the area planted to groundnut and the yields have declined (Dendere, 1987; Metelerkamp, 1987). The reasons for this and resultant low profitability include use of saved seed with low yield potential, late planting, low plant population densities, lack of basal fertilizer and the large labour requirement (Shumba, 1983; 1986; Metelerkamp, 1987; Natarajan and Zharare, 1994). Groundnut forms part of a rotation when land is relatively scarce, labour is plentiful and farmers are at least partly subsistence-orientated.

With favourable management, including incorporation of groundnut residues into the sandy soils that predominate in Zimbabwe, groundnut in the rotation can double the yield of the following maize, particularly when that maize is grown with little or no added N (Mukurumbira, 1985; McDonagh \textit{et al}., 1993; Hikwa and Waddington, 1998). There is a growing realization, however, that on most smallholder fields, where the grain and biomass yields from grain legumes are often poor and (as in Zimbabwe) where farmers remove from the field both the legume grain and most of the legume haulms, there may be little or no net N contribution to the soil by the legume and, hence, little improvement in the yield of subsequent maize (MacColl, 1989; Peoples and Craswell, 1992; Giller \textit{et al}., 1997; Hikwa and Waddington, 1998).

There are also doubts about the economic advantages of further investment by farmers in groundnut production. Work by Shumba \textit{et al}. (1990) showed that, in the Mangwende Communal Area of Zimbabwe, it was less profitable to invest in the most promising inputs and practices to increase groundnut productivity (improved seed, early planting and weeding, NPK fertilizer plus gypsum) than to invest in maize production.

In 1992–93 the authors began an experiment, on-station and on smallholder farms in Zimbabwe, to gauge the longer-term crop yield and soil fertility effects of the maize-groundnut rotation compared with continuous maize, both when inorganic fertilizer is applied to maize and when it is not. The yield and economic performance of the rotation was traced to decide whether groundnut yields and improved maize yields following a groundnut crop are sufficient to justify farmers using this rotation. The analysis concentrated on consequences for maize production because maize is the dominant food crop in the area.

\textbf{MATERIALS AND METHODS}

The experiment was planted at the AGRITEX Training Centre, Domboshava (17°35'S, 31°10'E; mean season rainfall = 880 mm) near Harare and on six smallholdings in the unimodal sub-humid rainfall zones of northeastern Zimbabwe. Three of the farm sites were in the Chinyika Resettlement Area.
(18°10’S, 32°20’E; mean rainfall = 812 mm) and three in and adjacent to the Chiduku Communal Area (18°30’S, 31°40’E; mean rainfall 822 mm).

In consultation with local farmers, the experimental sites were chosen to represent the principal maize fields cultivated by each farmer. Texture and chemical characteristics of the soils at the trial sites (from samples taken in 1992–94) are presented in Table 1. The soils are predominantly ustals (loamy sands, sandy loams and sandy clay loams) derived from granite. They have low pH (pH 4.2–4.7, in 0.01 m CaCl₂), carbon usually below 1%, low P, low cation exchange capacity (CEC) and low amounts of several cations. The sites had been cropped for various lengths of time, estimated to be between 12 years (Chinyika) and over 70 years (Chiduku) when the experiment began. Maize had been grown on each field in the year preceding the start of the experiment.

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 d after crop emergence and 70 kg N ha⁻¹ (ammonium nitrate) when the crop was approximately 60 cm tall. This provides 92 kg N, 17 kg P and 16 kg K ha⁻¹ a⁻¹.

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

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

T4. **Maize-Maize-Groundnut-Maize-Maize-Groundnut rotation (one crop of each per year)**. No fertilizer applied.

T5. **Continuous groundnut (year-after-year)**. No fertilizer applied.

The fertilizer treatments were derived from detailed agronomic monitoring and surveys of farmer practice in Mangwende Communal Area (Waddington et al., 1991).

Table 1. Soil texture and chemical properties for six farmers’ fields and the Domboshava research station planted with a maize-groundnut rotation, northern Zimbabwe, 1992–94.

<table>
<thead>
<tr>
<th>Farmer and site</th>
<th>Soil texture</th>
<th>pH (in 0.01 m CaCl₂)</th>
<th>C (%)</th>
<th>Mineralizable N (ppm)</th>
<th>P (Bray, µg g⁻¹)</th>
<th>K (µg g⁻¹)</th>
<th>Mg (µg g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domboshava</td>
<td>Loamy sand</td>
<td>4.5</td>
<td>0.43</td>
<td>24.1</td>
<td>41.9</td>
<td>31.8</td>
<td>12.5</td>
</tr>
<tr>
<td>G. Murombo, Chinyika</td>
<td>Loamy sand</td>
<td>4.3</td>
<td>0.52</td>
<td>18.6</td>
<td>1.3</td>
<td>78.0</td>
<td>20.0</td>
</tr>
<tr>
<td>V. Mutsindikwa,</td>
<td>Loamy sand</td>
<td>4.5</td>
<td>0.62</td>
<td>13.5</td>
<td>2.4</td>
<td>66.6</td>
<td>23.3</td>
</tr>
<tr>
<td>Chinyika</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Mudange, Chinyika</td>
<td>Sandy loam</td>
<td>4.3</td>
<td>0.42</td>
<td>3.7</td>
<td>3.5</td>
<td>60.5</td>
<td>20.0</td>
</tr>
<tr>
<td>E. Chinyanga, Chiduku</td>
<td>Sandy clay loam</td>
<td>4.7</td>
<td>1.35</td>
<td>41.6</td>
<td>0.4</td>
<td>169.0</td>
<td>77.9</td>
</tr>
<tr>
<td>J. Singano, Chiduku</td>
<td>Loamy sand</td>
<td>4.2</td>
<td>0.38</td>
<td>7.5</td>
<td>8.9</td>
<td>48.5</td>
<td>5.0</td>
</tr>
<tr>
<td>S. Chinyanga, Chiduku</td>
<td>Sandy clay loam</td>
<td>4.3</td>
<td>0.83</td>
<td>31.6</td>
<td>4.8</td>
<td>87.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>
The plot size was 10.8 × 10.5 m (113.4 m²) for both maize and groundnut. Seed of R215 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; on farm fields were managed jointly by farmers and research staff. The land was prepared using an ox-drawn mouldboard plough. 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.

Each year, the maize and groundnut grain yields were harvested from whole plot areas of 113.4 m². Maize grain yields were measured at 12.5% moisture content and groundnut grain as sun-dried mass. Above-ground, non-grain maize biomass (stover) was weighed from two adjacent middle rows (24 plants, 5.4 m²) per plot. Groundnut haulms were removed from the entire plot, weighed and 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 and stover yields.

Budgets for the maize-groundnut rotation were developed using methods given in CIMMYT (1988) and discounting procedures from Gittinger (1984). The discount rate for year 0 = 1, year 1 = 1/(1 + interest rate), year 2 = 1/(1 + interest rate)². In 1996 and 1997 the bank deposit interest rate was 23% per annum. Information on costs of seed and fertilizer for 1996 was obtained from suppliers. Labour data for maize and groundnut production, collected from six farmers in Chiduku during January and February 1997 and combined with older data from Mangwende Communal Area, were used at Domboshava and the on-farm sites. Cash inputs and outputs were valued at local prices, i.e., Harare prices for Domboshava, and Chinyika and Chiduku prices for the on-farm sites, and included all transport costs. Costs and labour data are reported with the budget tables.

RESULTS

Yield trends

Domboshava Training Centre. Over six years, the grain yields from continuous maize cropping without inorganic fertilizer (T2) decreased from 2.78 and 6.15 t ha⁻¹ in 1992–93 and 1993–94 to lows of 1.03 t ha⁻¹ in 1996–97 and 1.61 t ha⁻¹ in 1997–98 (Figure 1). The grain yield of continuous maize with fertilizer (T1) also declined (Figure 1). Irrespective of treatment, the lower yields were associated with rainfall extremes (low in 1994–95; high in 1997–98 and very high in 1996–97 (Figure 1)). Maize grain yield responses to the inorganic N fertilizer (calculated for 92 kg N ha⁻¹ compared with zero N applied) fell to between 25 and 30 kg grain (kg N)⁻¹ in the last four years (Table 2).

Grain yield was measured for two years of maize following groundnut in the
rotation (T3 and T4) (Figure 2). With no inorganic fertilizer applied to maize, the inclusion of a rotation with groundnut (T4) (producing 0.260–0.355 t ha\(^{-1}\) shelled grain) almost doubled the grain yield of the following maize crop (1995–96) from 2.46 t ha\(^{-1}\) to 4.61 t ha\(^{-1}\), an increase of 2.15 t ha\(^{-1}\) (Figure 2). It is estimated that, at the Domboshava site in 1995–96, at least 86 kg inorganic N ha\(^{-1}\) would have been needed with continuous maize to obtain an equivalent yield increase. In plots where inorganic fertilizer was applied to maize, the

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**Table 2.** Maize grain yield response to N fertilizer (kg grain (kg N)\(^{-1}\) calculated for 92 kg N ha\(^{-1}\) compared with zero N applied) in the maize-groundnut rotation at Domboshava, Zimbabwe.

<table>
<thead>
<tr>
<th>Cropping season</th>
<th>Continuous maize (T1)</th>
<th>Maize after groundnut (T3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992/93</td>
<td>41.6</td>
<td>—</td>
</tr>
<tr>
<td>1993/94</td>
<td>35.3</td>
<td>—</td>
</tr>
<tr>
<td>1994/95</td>
<td>25.2</td>
<td>—</td>
</tr>
<tr>
<td>1995/96</td>
<td>30.2</td>
<td>38.7</td>
</tr>
<tr>
<td>1996/97</td>
<td>26.9</td>
<td>24.1</td>
</tr>
<tr>
<td>1997/98</td>
<td>29.0</td>
<td>30.5</td>
</tr>
</tbody>
</table>
rotation (T3) produced even more additional maize grain yield (2.93 t ha\(^{-1}\)) (Figure 2). Small effects of the groundnuts on maize persisted in the second year of maize following groundnut (1996–97). These were larger where fertilizer was not applied (T4): 0.50 t ha\(^{-1}\), equivalent to a 49% increase in grain yield (Figure 2). Continuous groundnut cropping (T5) gave very low yields (falling from 0.470 t shelled grain ha\(^{-1}\) in 1992–93 to a low of 0.084 t ha\(^{-1}\) in 1996–97 (Figure 1).

**On-farm sites in Chinyika and Chiduku.** Across-year trends in maize grain yields at the on-farm sites are shown in Figures 3 and 4. Averaged over the six on-farm sites, the grain yield of maize without fertilizer (T2) declined from 2.16 t ha\(^{-1}\) in 1993–94, to 0.79 t ha\(^{-1}\) in 1994–95, to 0.75 t ha\(^{-1}\) in 1995–96 and to 0.50 t ha\(^{-1}\) in 1996–97, indicating a decline of approximately 0.07 t ha\(^{-1}\) a\(^{-1}\) for the last four years. There was, however, considerable variation in the yields from site to site (Figure 3) and in the response of maize yield to fertilizer over the years (Figure 4). As at Domboshava, groundnut grain yields for the continuous sole crop (T5) were low at all sites, averaging 0.25 t ha\(^{-1}\) in 1993–94, 0.189 t ha\(^{-1}\) in 1994–95, 0.07 t ha\(^{-1}\) in 1995–96, 0.073 t ha\(^{-1}\) in 1996–97 and 0.176 t ha\(^{-1}\) in 1997–98.
Maize-groundnut rotations on smallholder farms

Fig. 3. Grain yield of maize without inorganic fertilizer in the first five years of a trial at six on-farm sites in Chinyika and Chiduku, Zimbabwe, 1993–1998.

Fig. 4. Trends for maize grain yield, with inorganic fertilizer (92 kg N, 17 kg P, 16 kg K ha\(^{-1}\)) applied each year (●) and without inorganic fertilizer (○), and the grain yield response to 92 kg N ha\(^{-1}\) fertilizer (□), averaged over six on-farm sites in Chinyika and Chiduku, Zimbabwe, 1993–1998.
In the rotation (T3 and T4) the grain yield of groundnut was usually below 0.1 t ha$^{-1}$ (Table 3). There was a small benefit from growing groundnut after maize that had received NPK fertilizer (T3) compared with groundnut after unfertilized maize (T4). The above-ground haulm yields were below 0.5 t ha$^{-1}$ at most sites, however.

At five of the on-farm sites, maize was grown after the relatively poor groundnut crops (T3 and T4). With inorganic fertilizer the maize grain yields after groundnut (T3) declined at three sites compared with those for continuous maize (T1) (Figure 5). Without fertilizer, inclusion of groundnut in the rotation (T4) raised maize grain yields at all five sites (Figure 5) by an average 0.28 t ha$^{-1}$, but overall yields were only around 0.7 t ha$^{-1}$.

### Economic assessment

**Domboshava Training Centre.** An economic budget was calculated for the four crop + fertilizer combinations over the first year with groundnut in the rotation and the two subsequent years with maize, i.e. the period when benefits from groundnut might have raised system productivity (Table 4). The analysis takes the point of view of a farmer who, in 1994–95, has to choose a sequence of crops and fertilizer inputs. Because groundnut is a low-yielding crop with high labour requirements, the interpretation of the results depends on how family labour is valued. With or without inorganic fertilizer, returns over cash costs (i.e., seed and fertilizer) were higher for the rotation system (T3 and T4) than for the continuous maize (T1 and T2). This indicates that farmers short of cash may find the rotation attractive. However, when labour costs (valued using a local, casual-worker wage) were added, the continuous maize with fertilizer system (T1) showed higher returns than did the rotation (T3), while the returns for the rotation and continuous maize without fertilizer (treatments T4 and T2) were almost identical.

Groundnut grain yields need to be raised by only 117 kg ha$^{-1}$ with fertilized maize (T3) and just 13 kg ha$^{-1}$ without added fertilizer (T4) to increase the

### Table 3. Groundnut grain and above-ground haulm yields (kg ha$^{-1}$ air dry weight) when grown after maize in a maize-groundnut-maize rotation at six on-farm sites in Chinyika and Chiduku, Zimbabwe, 1995–96 or 1996–97.

<table>
<thead>
<tr>
<th>Farmer and site</th>
<th>With fertilizer on maize (T3)</th>
<th>Without fertilizer on maize (T4)</th>
<th>With fertilizer on maize (T3)</th>
<th>Without fertilizer on maize (T4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Murombo, Chinyika</td>
<td>64.8</td>
<td>111.1</td>
<td>484.0</td>
<td>583.0</td>
</tr>
<tr>
<td>V. Mutsindikwa, Chinyika</td>
<td>199.0</td>
<td>92.6</td>
<td>708.0</td>
<td>435.0</td>
</tr>
<tr>
<td>F. Mudange, Chinyika</td>
<td>63.9</td>
<td>98.3</td>
<td>215.2</td>
<td>380.1</td>
</tr>
<tr>
<td>E. Chinyanga, Chiduku</td>
<td>136.1</td>
<td>73.1</td>
<td>790.0</td>
<td>384.0</td>
</tr>
<tr>
<td>J. Singano, Chiduku</td>
<td>79.4</td>
<td>68.3</td>
<td>255.3</td>
<td>216.5</td>
</tr>
<tr>
<td>S. Chinyanga, Chiduku</td>
<td>67.5</td>
<td>24.7</td>
<td>159.6</td>
<td>62.6</td>
</tr>
<tr>
<td>Mean</td>
<td>101.8</td>
<td>78.0</td>
<td>435.4</td>
<td>343.5</td>
</tr>
</tbody>
</table>
discounted net benefits (DNBs) to those for continuous maize. Such increases should be readily achievable with minor improvements in groundnut management.

**On-farm sites in Chinyika and Chiduku.** Separate budgets were calculated for each of the five on-farm sites with maize after groundnut (T3 and T4), with similar objectives as for the Domboshava analysis (Table 5). In general the rotation was far less economic than at Domboshava. DNBs over cash costs were positive at four sites, but higher for the rotation (T3 and T4) at only two of the five sites i.e. those of Messrs. Mutsindikwa and Mudange, both in Bingaguru, Chinyika (Table 5). At the other sites they were much lower. For the rotation (T3 and T4) the DNBs over all costs were always negative or close to zero (Table 5). At Messrs Mutsindikwa’s and S. Chinyanga’s farms all cropping patterns had negative DNBs while at the other three sites it was most profitable to grow continuous maize with fertilizer (T1). At two of these sites it was calculated that groundnut grain yields would have to increase by more than 1 t ha$^{-1}$ with fertilizer (T3) and by almost 0.4 t ha$^{-1}$ without (T4) to rival continuous maize (Table 5). Such yields would be extremely difficult for smallholder farmers to achieve.
DISCUSSION

Potential and actual productivity of maize-groundnut rotations

The grain yields measured from plots of continuous maize without fertilizer (T1) in smallholder fields (0.5–0.8 t ha\(^{-1}\)) were far lower than the 1.5–2.4 t ha\(^{-1}\) recorded on-station, indicating the yield gap that remains between station and farm fields of similar soil type (sandy) in Zimbabwe. Maize yield responses to inorganic fertilizer at the on-farm locations were highly variable but, with adequate rainfall, the responses were moderate. Rainfall extremes reduced maize grain yields without fertilizer to critically low levels (approaching 0.5 t ha\(^{-1}\)).

Northern Zimbabwe generally has favourable biophysical conditions for groundnut growth and development. Williams (1979) found that a groundnut crop can fix 240 kg N ha\(^{-1}\) at Harare, and Mukurumbira (1985) doubled the grain yield of maize when part of a rotation with groundnut on sandveld soils at Marondera. These findings are confirmed by the on-station rotation (T3, T4) at
Domboshava. Even a poorly productive groundnut crop under simulated smallholder field conditions where most of the groundnut haulms (and maize stover) were grazed by animals, and particularly where inorganic fertilizer was not applied, almost doubled the grain yield of a following maize crop on a sandy soil derived from granite. Much of the rotation effect will be from leaf fall and the root system of groundnut (Giller et al., 1997). As groundnut may have a large biomass of green haulms at harvest, incorporation of these can dramatically improve yields of subsequent maize (e.g. McDonagh et al., 1993). However, this is unlikely to be practised by smallholder farmers. The whole plants are usually removed from the fields, and pods shelled at the homestead. Haulms are then fed to livestock.

The on-farm results confirm reports by Shumba (1983; 1986), Shumba et al. (1990) and Hikwa and Waddington (1998) of the far poorer performance of groundnut crops on smallholder fields in Zimbabwe than on research stations. Some of the factors mentioned in those earlier studies, particularly the low plant densities and lack of basal fertilizer, were partly responsible. Soil P was far lower at all on-farm sites than at Domboshava station (Table 1) and to improve groundnut growth would require P supplementation. The extremely poor groundnut growth and yields attained in this experiment (less than 0.5 t ha\(^{-1}\) of above-ground haulms) and the low maize yields suggest that, with current levels of management on smallholder farms in northeast Zimbabwe, the maize-groundnut rotation may offer little improvement in the sustainability of yield.

**Yield variability with rainfall**

On-farm yield variation across years was closely associated with rainfall. The higher yield in 1993–94 was probably due to high mineralization and carryover effects from the previous two years which were dry. In 1994–95 the very low response to fertilizer was due mainly to intermittent drought during early development of the crops and severe drought throughout grain filling. Seasonal rainfall totals of just 290 mm to 355 mm were recorded for 1994–95. The relatively high response to fertilizer N (29 kg grain kg N\(^{-1}\)) calculated for 1995–96 was probably due to some available N remaining in the soil from that applied in the previous dry year. In contrast to the dry conditions of 1994–95, both 1995–96 and 1996–97 were wet. The rainfall for 1995–96 was 500–800 mm in Chiduku and over 1100 mm in Chinyika. The lowest grain yields without fertilizer (T2) (an average of 0.5 t ha\(^{-1}\) in 1996–97) were recorded in an extremely wet year with very heavy rain throughout January and early February. Total rainfall for the season was 963 mm in Chinyika, and 808 mm in Chiduku. These low yields were probably partly the result of leaching of nutrients and denitrification. Almost certainly, however, competition from weeds played a major role. Because of waterlogging at some sites, particularly in 1996–97, farmers could not weed their lands. Waterlogging of sandy granitic soils in Zimbabwe, due to clay enriched subsoils, is a common occurrence. The field belonging to Mr. Mutsindikwa in Bingaguru was waterlogged through February and March 1996 and January to
Table 5. Discounted net benefits (net present value; Z$ ha\(^{-1}\)) over two years for a groundnut and maize rotation at five on-farm sites in Chinyika and Chiduku, Zimbabwe, 1995–96 to 1997–98. All calculations are in Zimbabwe dollars with prices from 1997*.

<table>
<thead>
<tr>
<th>Name of farmer, and type of costs</th>
<th>With inorganic fertilizer</th>
<th>Without inorganic fertilizer</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous (T1)</td>
<td>Rotation (T3)</td>
<td></td>
</tr>
<tr>
<td>V. Mutsindikwa</td>
<td>351</td>
<td>1004</td>
<td></td>
</tr>
<tr>
<td>Over-cash costs</td>
<td>270</td>
<td>446</td>
<td>Rotation (T3 and T4) gives higher DNB than continuous maize (T1 and T2), with and without fertilizer. Cash-constrained farmers should use groundnut-maize rotation.</td>
</tr>
<tr>
<td>Overall costs</td>
<td>-1500</td>
<td>-1618</td>
<td>DNBs are negative for all crop patterns indicating not profitable. Without fertilizer the rotation (T4) is less unprofitable so is recommended. Small achievable increases in groundnut yield (22.5 kg ha(^{-1})) will pay for the rotation with fertilizer.</td>
</tr>
<tr>
<td>E. Chinyanga</td>
<td>8356</td>
<td>2539</td>
<td></td>
</tr>
<tr>
<td>Over-cash costs</td>
<td>2171</td>
<td>713</td>
<td>Continuous maize (T1 and T2) gives much greater DNBs than does rotation, especially where fertilizer is applied (T1).</td>
</tr>
<tr>
<td>Overall costs</td>
<td>6092</td>
<td>562</td>
<td>DNBs are very large for continuous maize with fertilizer (T1). DNBs for rotation are low and negative without fertilizer (T4). Increases in groundnut yield needed to pay for rotation are large (1151 kg ha(^{-1}) with fertilizer and 370 kg ha(^{-1}) without) and difficult to achieve on-farm. Continuous maize, preferably with fertilizer (T1), is recommended.</td>
</tr>
<tr>
<td>G. Murombo</td>
<td>7102</td>
<td>144</td>
<td>Continuous maize (T1 and T2) gives much greater DNBs than does the rotation, especially where fertilizer is applied (T1).</td>
</tr>
<tr>
<td>Over-cash costs</td>
<td>2245</td>
<td>783</td>
<td>DNBs are negative for rotation with and without fertilizer (T3 and T4). Increases in groundnut yield needed to pay for the rotation are large (1017 kg ha(^{-1}) with fertilizer and 397 kg ha(^{-1}) without) and difficult to get on-farm. Continuous maize, preferably with fertilizer (T1), is recommended.</td>
</tr>
</tbody>
</table>
The rotation without inorganic fertilizer (T4) gives higher DNBs than does continuous maize (T2). Cash constrained farmers should use the groundnut-maize rotation. DNBs are large for continuous maize with fertilizer (T1). DNBs for rotation are low, and negative without fertilizer (T4). Increases in groundnut yield needed to pay for the rotation are large (396 kg ha\(^{-1}\) with fertilizer) and difficult to achieve on-farm. Continuous maize with fertilizer is recommended.

DNBs are all near zero or negative indicating not profitable. Continuous maize with fertilizer (T1) is the least profitable and without fertilizer (T2) is the most profitable.

DNBs are all very negative indicating not profitable. Continuous maize without fertilizer (T2) has lowest losses.

*11.3 \(Z\$ = 1\) US\$, May 1997

Price and labour data for the on-farm sites, as presented in Table 5 were as for Domboshava except:

Local selling price white maize early 1997 = Z\$1570 t\(^{-1}\)

Local selling price shelled groundnut early 1997 = Z\$5240 t\(^{-1}\)

Compound D fertilizer price early 1997 = Z\$2880 per t\(^{-1}\)

Ammonium nitrate fertilizer price early 1997 = Z\$3000 t\(^{-1}\)

Maize seed price 25 kg ha\(^{-1}\) = Z\$185.00

Using saved groundnut seed price 70 kg ha\(^{-1}\) = Z\$367.00.
April 1997. This reduced the growth of groundnut and maize, and the response of maize to the fertilizer. At other sites, heavy, leaching rains produced symptoms of other nutrient deficiencies (especially Mg) when NPK fertilizer was applied. Symptoms of Mg deficiency were especially severe at Mr. J. Singano’s field in Chiduku and this was confirmed by previous soil chemical analysis (Table 1). To understand better the long term consequences of on-farm maize-grain legume (including groundnut) rotations, the authors are presently undertaking simulations over long-term rainfall records using the Agricultural Production Systems Simulator (APSIM) model (McCown et al., 1996).

**Economic assessments**

Because of the low groundnut yields, minor yield improvement for on-farm maize following groundnut, and the large labour cost associated with growing the groundnuts, the rotation was far less profitable than continuous maize, especially when the maize was grown with fertilizer. In the economic budgets, the profitability of groundnut was sensitive to how the labour requirements for producing groundnut are valued. Pricing labour for groundnut production is difficult because normally almost all the tasks are carried out by female members of the household. In calculations here labour was assigned either a zero monetary value (benefits over cash costs only) or the local casual-worker wage rate in Chiduku or Chinyika. The latter rate almost certainly overestimates the monetary value of female labour used to produce groundnuts. However, extremely low or zero monetary values for labour are necessary for the rotation to be remotely profitable. The low yield, marginal to zero profitability and high labour cost of groundnut production found in this study explain the general trend by farmers in Zimbabwe to grow smaller areas of groundnut. At some on-farm sites, the extra groundnut grain yields required to match the profitability of the continuous maize with fertilizer are over 1 t ha⁻¹ and would be virtually impossible to achieve.

**Alternative legumes and inputs**

The experimental results emphasize the need for research to (i) increase the yield of groundnut on smallholder fields, and (ii) reduce the labour costs of its production, without adding much to cash costs. Although smallholder groundnut crops in Zimbabwe rarely respond well to added fertilizers, some promising interventions to increase yields involve improving the base soil fertility of groundnut fields in rotations (Metelerkamp, 1987). Liming, the application of gypsum, and use of animal manure in rotations are helpful. Hava (1964) showed that in Zimbabwe groundnut responds to the addition of Ca and S on granitic sandy soils, and recent results from smallholder groundnut fields (Chikowo, et al., 1997) show that applications of P and Ca will increase yields. Calculations in this study, however, indicate that it would be difficult to raise them sufficiently to make the crop profitable.

Annual-legume rotations remain a class of technology with great potential to address soil infertility and improve the sustainability of smallholder cropping.
systems in southern Africa (Snapp et al., 1998; Hikwa and Waddington, 1998). However, because of the poor performance of groundnut on Zimbabwean smallholdings and the general difficulty of improving performance substantially through realistically affordable management and inputs, the search must continue for additional, more robust grain legumes that farmers want to grow for food and income (Giller et al., 1998; Hikwa and Waddington, 1998). In this regard, promiscuous soybean is generating great interest among smallholders as a cash and food crop (Pompi et al., 1998; Mpepereki et al., 2000). Velvet bean (Mucuna pruriens var utilis), a consistent producer of above-ground biomass on sandy soils in northern Zimbabwe (Hikwa and Waddington, 1998), presents plant breeders with a great opportunity to turn this into a favoured grain legume by reducing the amounts of L-dopa in the seed. Nevertheless, in the current socio-economic situation in southern Africa it is becoming less likely that smallholder farmers can spontaneously acquire the inputs needed to grow any of these legumes well. Agricultural research is now generating and presenting information that will help to justify policy decisions concerning input support and public-good external investment into inputs such as lime, P and seed for smallholder farmers in southern Africa. After such investments, it could be that smallholder farmers would grow legumes sufficiently widely to add enough N and organic matter to constitute a major contribution to sustained soil fertility.

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