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ORIGINAL PAPER

Raising the productivity of smallholder farms under semi-arid conditions by use of small doses of manure and nitrogen: a case of participatory research

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Abstract Participatory on-farm trials were conducted for three seasons to assess the benefits of small rates of manure and nitrogen fertilizer on maize grain yield in semi-arid Tsholotsho, Zimbabwe. Two farmer resource groups conducted trials based on available amounts of manure, 3 t ha^{-1} (low resource group) and 6 t ha^{-1} (high resource group). Maize yields varied between 0.15 t ha^{-1} and 4.28 t ha^{-1} and both absolute yields and response to manure were strongly related to rainfall received across seasons ($P < 0.001$). The first two seasons were dry while the third season received above average rainfall. Maize yields within the seasons were strongly related to N applied ($R^2 = 0.77$ in season 1, and $R^2 = 0.88$ and 0.83 in season 3) and other beneficial effects of manure, possibly availability of cations and P. In the 2001–2002 season (total rainfall 478 mm), application of 3 and 6 t ha^{-1} of manure in combination with N fertilizer increased grain yield by about 0.14 and 0.18 t ha^{-1}, respectively. The trend was similar for the high resource group in 2002–2003 although the season was very dry (334 mm). In 2003–2004, with good rainfall (672 mm), grain yields were high even for the control plots (average 1.2 and 2.7 t ha^{-1}). Maize yields due to manure applications at 3 and 6 t ha^{-1} were 1.96 and 3.44 t ha^{-1}, respectively. Application of 8.5 kg N ha^{-1} increased yields to 2.5 t ha^{-1} with 3 t ha^{-1} of manure, and to 4.28 t ha^{-1} with 6 t ha^{-1} of manure. In this area farmers do not traditionally use either manure or fertilizer on their crops, but they actively participated in this research during three consecutive seasons and were positive about using the outcomes of the research in future. The results showed that there is potential to improve livelihoods of smallholder farmers through the use of small rates of manure and N under semi-arid conditions.

Keywords Cattle manure · Maize yields · Nitrogen fertilizer · On-farm research · Smallholder farming

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Introduction

Poor soil fertility is the fundamental biophysical cause of declining per capita food production on smallholder farms in Africa (Sanchez 2002). Recommendations for nutrient management, and in particular fertilizer use technologies, have rarely been implemented by smallholder farmers (Dimes et al. 2004a, b). High costs of fertilizers, lack of credit, delays in the delivery of fertilizers and poor transport and marketing infrastructure serve as disincentives to fertilizer use by smallholder farmers (Buresh and Giller 1998). As a result, fertilizers are sparsely used, grain yields and per capita food production are declining, and food security is worsening, particularly in the extensive semi-arid areas of Africa. The poor adoption of improved fertility management methods is attributable to several reasons, including: (i) inappropriate recommendations that fail to consider rainfall risks and investment capacity of smallholder farmers, (ii) blanket recommendations that overlook the spectrum of farming objectives and returns on investment that typifies smallholder farming systems, and (iii) inappropriate marketing of fertilizers to smallholder farmers (Dimes et al. 2004a, b). Several authors have made the case for fertility options rather than blanket recommendations that do not take into account the local variability in soil fertility (Giller et al. 2006) and largely ignore socio-economic factors (Ahmed et al. 1997; Rohrbach 1999; Snapp et al. 2003).

In semi-arid areas of Zimbabwe the soils are inherently infertile and have a low potential to sustain agricultural production under continuous cultivation (Mapfumo and Giller 2001). The soils are particularly deficient in nitrogen, phosphorus and sulphur and the soil fertility on smallholder farms in Zimbabwe continues to decline (Hikwa et al. 2001). Maintenance of soil fertility is the key to sustaining productivity of smallholder agriculture in sub-Saharan Africa (Brinn et al. 1999).

The nutrient resource most readily available to smallholder farmers is cattle manure although the small nutrient contents of manures makes them poorly effective in improving crop yields (Mugwira and Murwira 1997, 1998). One of the greatest research challenges is to develop technologies that are effective within farmer resource constraints, resource levels and acceptable risk (Snapp et al. 1998, 2003). Recent research emphasizes options that combine mineral fertilizer and organic manures (Ahmed et al. 1997; Palm et al. 2001; Nyathi et al. 2003; Snapp et al. 2003). Research approaches are also required that help to build quality farmer–researcher partnerships using participatory research methods that can make technology testing more realistic (Snapp et al. 2003). Smallholder farmers are more likely to accept the results and recommendations of research if they have been engaged in developing the recommendations under their farming environment. However, site and season specificity of on-farm experimentation remains an issue in interpretation and extrapolation of results, and the case for simulation modelling as an analytical tool in participatory research, especially in the area of fertility management, has been documented (Rohrbach 1999; Dimes et al. 2002a) and applied in smallholder farming systems in Africa (Shamudzarira et al. 2000; Dimes et al. 2002b). Carberry et al. (2004) reported the use of a simulation model with farmers and researchers at Tsholotsho, Zimbabwe, to explore the climatic risks associated with the application of various crop management technologies and as an aid to designing farmer experimentation. In this paper, we report the results of the ensuing 3 years of participatory research in developing and testing recommendations for improving soil fertility. The main objective of the participatory research was to develop strategies for improving maize yield under farmer conditions in semiarid environments, by combining low rates of manure and mineral nitrogen fertilizer. A further objective was also to assess farmer participation dynamics and how successful engaging farmers could be in developing soil fertility management strategies.

Materials and methods

Site characteristics

Rainfall

On-farm trials were conducted in Tsholotsho District, southwestern Zimbabwe. Tsholotsho is located in Natural Farming Region IV. This natural farming region is characterized by semi-arid climatic conditions and annual uni-modal rainfall of between 450 mm and 650 mm (long-term average, 590 mm). The duration of the rainy season is from October/November to March/April and is typically characterized by sporadic, heavy rainstorms, with periodic dry spells. It is followed by a cool to warm dry season from May to September.

Soils

On farm trials were carried out in two adjacent villages of Tsholotsho District, namely Mahangule and Mkhubazi. The two villages have similar soils and vegetation. The most common soil type is the deep (>150 cm) Kalahari sand (Ustic Quartzipsamment, 93% sand, 4% clay, 3% silt, in the 0–11 cm layer) originating from Aeolian sand parent material (Moyo 2001). The farmers commonly refer to the soil by its local name, *ihlabathi*. Other soils in the area include Aridic Haplustalfs (local name, *iphane*) and mixed *ihlabathi*and *iphane* though these are not common. The pH (0.01 M $CaCl_2$) of the soils was slightly acidic (5.5–5.8 in the 0–11 and 11–30 cm, respectively), organic carbon content less than 1%, and cation exchange capacity (CEC) less than 5 $cmol_c\ kg^{-1}$. Base saturation was 56% in the 0–11 cm layer. Exchangeable Ca, Mg, Na and K in the 0–11 cm layer were 0.9, 1.2, 0.07 and 0.33 $cmol_c\ kg^{-1}$, respectively (Moyo 2001).

Farming system

The farming system in Mkhubazi and Mahangule is semi-extensive mixed farming, involving goat and cattle production, and cultivation of drought resistant crops. Both crop and livestock productivity in the smallholder-farming sector is poor (Hikwa et al. 2001). The farmers grow maize (*Zea mays*L.), sorghum (*Sorghum bicolor*(L.) Moench) and pearl millet [*Pennisetum glaucum*(L.) R.Br.] as the major cereal grain crops. Maize and sorghum are normally planted with the first rains from around mid-November. Normal fertility management practice is to apply amendments (mainly manure) to the maize crop, and plant sorghum the following season (Carberry et al. 2004). Groundnut (*Arachis hypogaea*L.), Bambara groundnut (*Vigna subterranea* (L.) Verdc) and cowpea (*Vigna unguiculata* L.) are the three legumes grown, but areas sown to legume each season are generally small (Ahmed et al. 1997), and legumes receive less than 5% of the applied nutrients (Mapfumo and Giller 2001).

Background to the participatory action research

The Mkhubazi farmer group had worked together with researchers since 1999, (equal number of farmers from each village). In 2001, farmers and researchers jointly participated in using a simulation model (APSIM, Keating et al. 2002) to assess the climatic risks associated with the application of various crop management technologies in the farmers' cropping system (Carberry et al. 2004). Following this interaction, the majority (22 out of 26) of the farmers were keen to carry out experiments using cattle manure and small rates of fertilizer. Out of the 22 farmers, 11 had manure available. At the beginning of the 2001–2002 cropping season, on-farm trials were established to test maize response to small doses of manure, with and without small rates of N fertilizer.

The farmers divided themselves into two groups; a lower resource group (LRG) that could afford one cart of manure per ha (equivalent to ten standard wheel barrows full of manure), and a higher resource group (HRG) that could afford two carts per ha (20 wheel barrows). When the amounts were translated to rates they were equivalent to 3 t ha^{-1} (one cart) and 6 t ha^{-1} (two carts) of manure, respectively. It should be noted that while this division reflected the relative resource capacities of the farmers in the group, the manure application rates were substantially lower than existing extension recommendations; 10 t ha^{-1} applied annually or 40 t ha^{-1} applied every 4 years in high rainfall areas and 8–20 t ha^{-1} for semi-arid areas (Mapfumo and Giller 2001), hence, the use of the term 'small' in describing the manure applications. In 2001–2002, the lower resource group consisted of four farms, increasing to eight farms in the second and third cropping seasons. The higher resource group consisted of seven farms throughout.

Farmers selected parts of their fields for experimental plots. They were asked to select plots that had previously been planted to a cereal with no fertility inputs, with relatively uniform soil. The plot size was agreed after lengthy discussions with the farmers who had raised concern about typical research plots, which they considered too small. The farmers unit of area measurement was an acre and they agreed on a total plot size of one quarter of an acre (0.1 ha), which they could weed and harvest in one day. The experimental design was agreed with the farmers and began as simple paired plots during the 2001–2002 cropping season. Each farmer hosted one replicate of the experiment according to the resource group to which they belonged. At the end of each cropping season the results for each group member were presented and discussed. This generated debate as the farmers discussed lessons learnt and possible explanations for the results. From these meetings farmers came up with more ideas for further experimentation, hence the number of treatments increased each season. Plot sizes were reduced but were still substantially larger than typical research plots. Table 1 summarizes the development of the experiments and the changes in treatments from the first to the third season.

In season one, treatments consisted of paired plots treated with small doses of manure. The HRG applied 6 t ha^{-1} while the LRG applied 3 t ha^{-1}. The manure was applied in November prior to ploughing. To one of the paired plots, 25 kg ha^{-1} ammonium nitrate (AN, 34.5% N) was applied as top-dressing at approximately 4–6 weeks after planting. Twenty-five kg ha^{-1} of ammonium nitrate was the amount of fertilizer that farmers agreed they could afford to buy. In the second season, the number of plots increased to four (total area remained 0.1 ha) after the farmers realized that during the first season there was no control treatment for comparison, although in some cases surrounding crop areas could be used for comparison. A fertilizer treatment was also included to show how the manure treatments compared with the recommended fertilizer practice. Two further treatments were added in the third season. A plot with recommended rate of Compound D (containing 7%, 6% and 6% of N–P–K, respectively) and a small rate of AN, and another plot with small rates of both AN and Compound D. At this stage the farmers better understood the research process and these treatments were added in order to increase the number of options from which the farmers could choose.

Table 1 Experimental treatments applied in each season from 2001 to 2004

Season 1 (2001–2002)	Season 2 (2002–2003)	Season 3 (2003–2004)
1. Manure only	1. Manure only	1. Manure only
2. Manure + low rate ammonium nitrate[a] at a rate of 25 kg ha^{-1} (8.63 kg N)	2. Manure + AN at 25 kg ha^{-1}(8.63 kg N)	2. Manure + AN at 25 kg ha^{-1} (8.63 kg N)
	3. Recommended rates: 150 kg ha^{-1}Compound D[a] (10.5 kg N) and 150 kg ha^{-1} AN (51.75 kg N)	3. Recommended rates basal Compound D+ AN each 150 kg ha^{-1} (total 62.25 kg N)
	4. Control	4. Control
		5. Low rates Compound D and AN each 25 kg ha^{-1} (total 12.13 kg N)
		6. High rate of Compound D and low rate of AN (total 19.13 N)

[a]Ammonium Nitrate contains 34.5% N, Compound D contains 7% N, 6% P and 6% K. Treatment plot sizes decreased as the number treatments increased, but total trial plot area remained 0.1 ha per farm

Trial protocol

The maize seed variety planted each season was a short season hybrid recommended for the dry regions. In year 1 and 2 this was SC401, and in year 3, SC403. Farmers were provided with the appropriate amounts of seed and fertilizer. The varieties are available to the farmers for purchase every season. The farmers were also provided with rain gauges and a field manual prepared for the project, outlining the agreed experimental methods, which were translated into the local language during the first season. Each manual guided the farmers on record keeping (rainfall, activity date, problems and any other relevant information). A locally recruited field assistant provided further support throughout the season. Apart from site selection, pegging and training on fertilizer application, all other activities, such as land preparation (farmers plough using the ox-drawn moldboard plough), manuring, planting, weeding and pest control were undertaken by the farm household following their normal farm management practice. At the end of the season, farmers were assisted in harvesting the experimental plots and weighing the maize grain and stalk yields. A sub-sample of 3–4 maize plants and cobs per treatment plot was taken for moisture determination in the laboratory and in the third season the samples were also analysed for N and P uptake. Grain yields are reported at 12.5% moisture content.

In seasons 2 and 3, soil samples were collected from the experimental plots to determine organic carbon, nitrogen and phosphorus. The experimental plot was divided into a grid of three equal sections. Soil samples were then collected in the 0–30 cm layer, from three equally distributed points within each section using sampling tubes. A composite sample was then created by thoroughly mixing and sampling each time until about 1.5 kg of soil had been collected. Organic carbon, total N, total and available P were analysed using methods outlined by Okalebo et al. (1993). Soil nitrate-N was determined using the colorimetric method of Anderson and Ingram (1993). In addition a sample of each farmer's manure was taken in each season to determine total and available N and P, and organic carbon (OC). The number of fields harvested within each resource group varied across the three seasons. The reduction in the number of harvested fields was mainly due to crop failure as a result of low rainfall, and an increase was due to the expansion of the group as new members joined. Table 2 shows the numbers of farms within the resource groups, the number of harvested farms within each group and the location of the harvested fields for that season (main, home). A home field is smaller in area (about 0.2–1 ha) compared with the main field, and it is usually located just behind the homestead. The main field is usually a distant field (up to 5 km away from the homestead) and the whole field can be in excess of 5 ha in area. Some farmers own 8 ha of land as main fields.

Statistical analysis

The maize yield data was analysed using the method of residual maximum likelihood (REML) included in the statistical software package Genstat 6.1. The choice of REML was based on the fact that the model includes fixed and random factors, accounts for more than one source of variation in the data and provides estimates for treatments effects in unbalanced treatment

Table 2 Number of farms, field types and maize crops harvested in the respective farmer resource groups each season

Season	Lower resource farms			Higher resource farms		
	No. of farms	Field type		No. of farms	Field type	
		Main	Home		Main	Home
2001–2002	4	1 (0)	3 (3)	7	6 (4)	1 (1)
2002–2003	8	3 (0)	5 (3)	7	6 (3)	1 (1)
2003–2004	8	3 (3)	5 (4)	7	6 (4)	1 (1)

Numbers in brackets represent the number of fields harvested from the respective field types

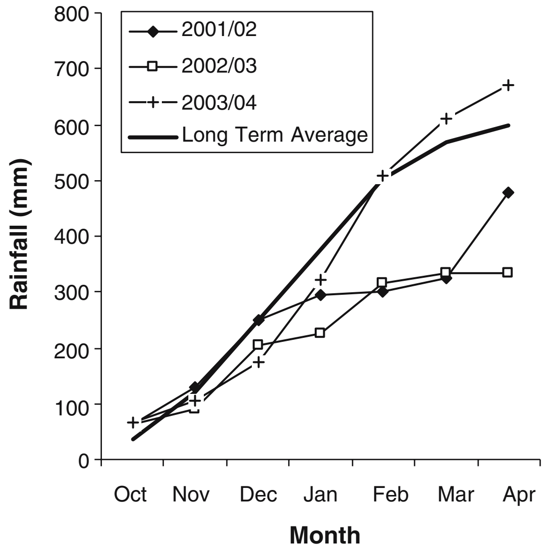

Fig. 1 Cumulative total rainfall for three seasons from 2001 to 2004 in Tsholotsho District, Zimbabwe. The long-term average total precipitation is 590 mm per annum

designs. The on-farm data met these criteria. In the REML linear mixed models, two model components need to be defined. The random model component defines the random terms, while the fixed model component defines the systematic or fixed terms. Random factors can be included in either the random or the fixed model component, depending on the objective of the analysis (Genstat Guides, Statistics. http://www.genstat.com). Season was included in the fixed model so that differences between seasons could be tested.

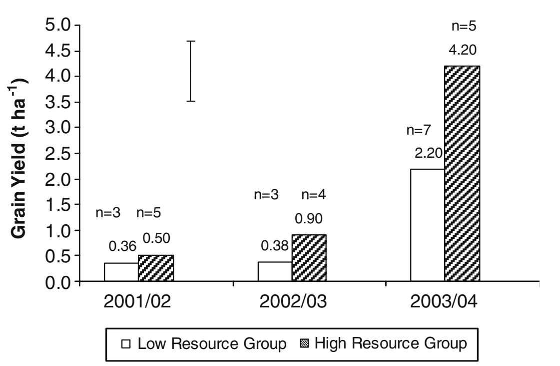

Fig. 2 Mean seasonal maize grain yield for the manure and manure + N treatments, Mkhubazi 2001–2004. Error bars represent standard errors of differences between the predicted means of the manure by season yields

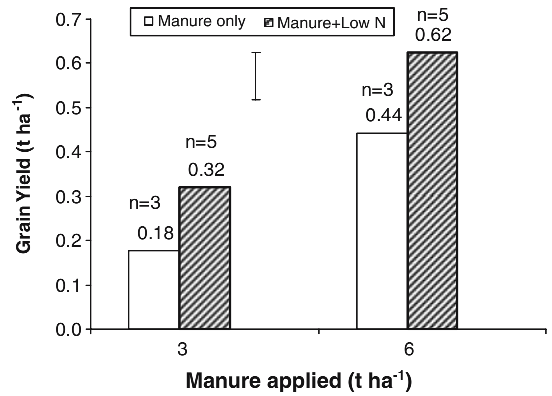

Fig. 3 Mean maize grain yield from Mkhubazi, Tsholotsho, 2001–2002 season. The two levels of manure applied represent the low (3 t ha^{-1}) and high (6 t ha^{-1}) resource groups. Error bars represent standard errors of differences between means of the treatments

The dialogue box in Genstat 6.1 for the REML Linear Mixed Model requires that both the fixed and the random model terms be defined, respectively. Hence, these terms are defined in the following paragraphs that show the structure of the statistical analyses. The models were defined following Genstat notation and syntax. There were four statistical analyses, one analysis for the two manure treatments that were present over the three seasons (Fig. 2), and one analysis for each season (Table 5 and Figs. 3, 5, 6) that included the corresponding treatments, respectively.

The linear mixed model, used to analyse the seasonal effects on the two manure treatments

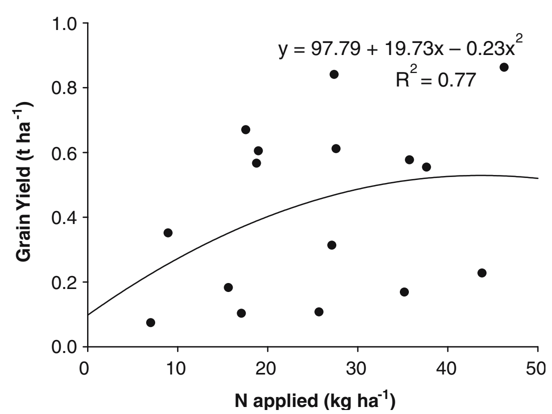

Fig. 4 Maize grain yield response to N applied, Mkhubazi 2001–2002 season

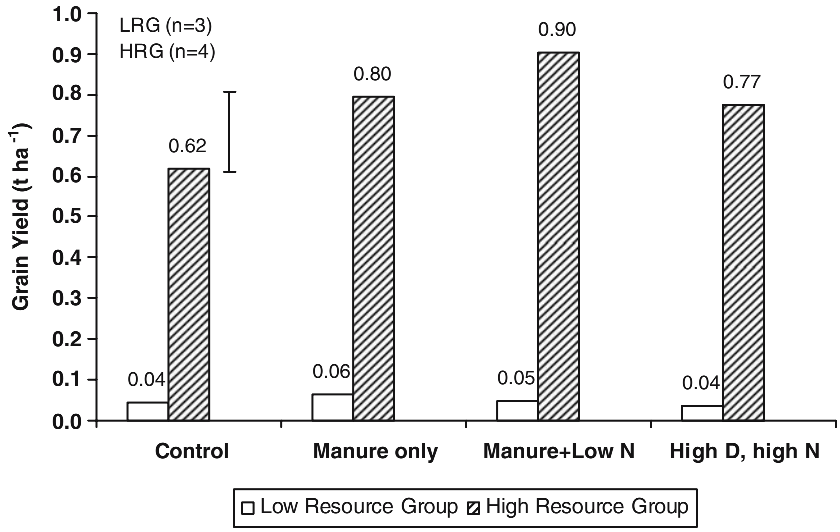

Fig. 5 Mean maize grain yield, Mkhubazi 2002–2003 season. The low resource group (3 t ha^{-1}) yields were close to zero, mainly due to low rainfall (Fig. 1). Error bars represent standard errors of differences between means of the treatments

that were present across all three seasons (Table 1) had the following components and terms:

Response: Yield
Fixed model: Constant + Resource Group + Treatment + Season + Resource Group . Treatment + Resource Group . Season + Treatment . Season + Resource Group . Treatment . Season
Random model: Farmer + Field location (type) + Relative planting date.

Because the set of treatments was not the same for each season (Table 1) the REML linear mixed model was used to analyse the data for each season separately, and the terms in the model were defined as:

Response: Yield
Fixed model: Constant + Resource Group + Treatment + Resource Group . Treatment
Random model: Farmer + Field Location + Relative planting date.

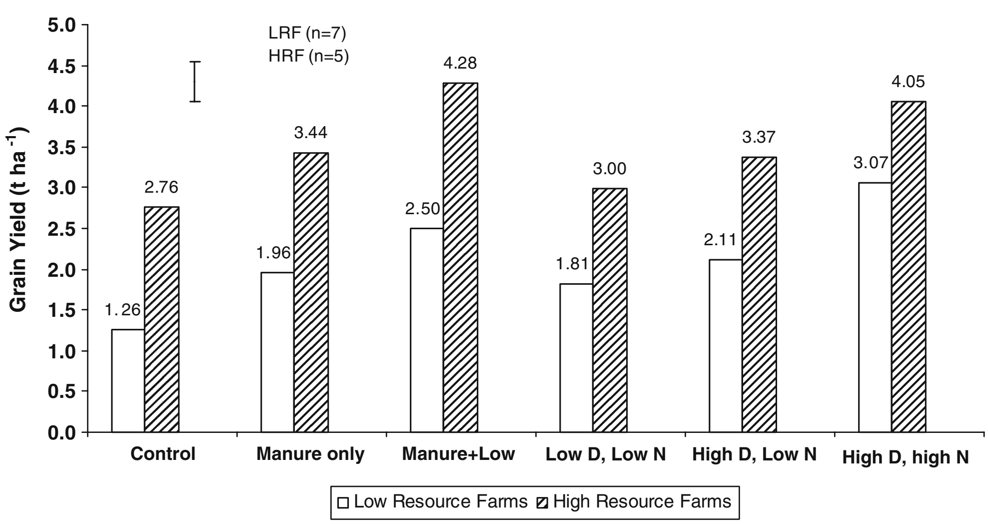

Fig. 6 Mean maize grain yield, 2003–2004 season, Mkhubazi. Error bars represent standard errors of differences between means of the treatments

Table 3 Chemical characteristics of the soil from the experimental fields and the manure belonging to the different farmer resource groups

Resource group	Field type	Soil (0–30 cm depth)				Manure			
		C (%)	% N	% P	pH_{H_2O}	C (%)	%N	% P	pH_{H_2O}
Low resource group (3 t ha^{-1} manure)	Home	0.53	0.03	0.03	5.0	5.4	0.38	0.08	8.8
	Main	0.49	0.04	0.03	5.4				
High resource group (6 t ha^{-1}manure)	Home	0.38	0.04	0.03	4.8	7.3	0.51	0.1	9.1
	Main	0.51	0.04	0.03	6.2				

Soil type and previous crop were tested as random variables but were not significant in accounting for any of the unexplained variability. The results of the statistical analyses are also shown as standard errors of differences in the graphs.

Results

Field characteristics and manure quality

Home fields for the LRG had larger organic carbon content than main fields but lower soil pH (Table 3). For this sample of farmers' fields, the measured parameters indicated slightly better soil fertility status for the LRG farms compared with that of the HRG farms. However, all soils had a low content of organic matter ($<0.6\%$ C) and total N ($\leq 0.04\%$ N) and thus had a poor capacity to supply N for crop growth. The manures used in experiments had N contents consistently below 1% and are considered to be of poor nutrient quality (Murwira et al. 1998).

Rainfall

Total rainfall and its seasonal distribution varied considerably between the three cropping seasons (Fig. 1). The first cropping season (2001–2002) started well with average rainfall pattern for October to December, but then there was a 3 month dry spell, and despite above average rainfall in April, seasonal rainfall was substantially below average at 478 mm. The second cropping season (2002–2003) was the driest overall with a total rainfall of only 334 mm, attributable to an almost dry post-sowing January, coupled with an early end to the rainfall in February. The third season (2003–2004) was the most favourable for crop growth with an above average total of 672 mm. Although there was below average rainfall from October to December, rainfall was above average in each of the subsequent months up to and including April.

Experimental results and farmer evaluation

Harvested plots

A total of 116 observed plots were harvested over the three experimental seasons (Table 4). A summary of the average yields obtained from the different treatments across the three seasons for both the LRG and the HRG is given in Table 5. The HRG harvested more plots during the dry seasons (2001–2002 and 2002–2003) compared with the LRG.

Table 4 Harvested plots per season, farm and treatment

Season	LRG			HRG			Total harvested plots
	Treatment	Farms	Harvested plots	Treatment	Farms	Harvested plots	
2001–2002	2	3	6	2	5	10	16
2002–2003	4	3	12	4	4	16	28
2003–2004	6	7	42	6	5	30	72
Total		13	60		14	56	116

Table 5 Summary of maize grain yields from the different treatments across the three cropping seasons

Season	Treatment	Mean maize grain yield (t ha^{-1})		*P*-value		Sed	
		LRG	HRG	Treatment	Manure rate	Treatment	Manure rate
2001–2002	Manure only	0.18	0.44				
	Manure + N	0.32	0.62	< 0.001	0.075	0.053	0.084
2002–2003	Manure only	0.06	0.62				
	Manure + N	0.05	0.77				
	High D, high N	0.04	0.80				
	Control	0.04	0.91	0.057	< 0.001	0.098	0.190
2003–2004	Manure only	1.96	3.44				
	Manure + N	2.50	4.28				
	High D, high N	3.07	4.06				
	Control	1.26	2.76				
	High D, low N	2.11	3.37				
	Low D, low N	1.81	3.00	< 0.001	0.014	0.239	0.725

Performance of maize yield for the farmer resource groups across the seasons

As the manure only and manure with N treatments were tested in each of the three seasons, a comparison of maize grain yield across the three seasons was done for these treatments for the two farmer resources groups (Fig. 2). In the third season, which had above average rainfall, maize yields were in excess of 2 t ha^{-1}, significantly higher ($P < 0.001$) than the average yields in the previous seasons that had below average rainfall and severe mid-season drought periods. In seasons 2 and 3, maize yields in the fields of the HRG farmers were significantly larger than yields in the fields of the LRG farmers ($P < 0.01$), but this was not the case in season 1. The soil chemical properties could not explain the yield difference because there were no significant soil chemical differences between LRG and HRG fields. However, the HRG farmers applied twice as mach manure as farmers in the LRG. Also, the HRG manure contained more N, 0.51% N compared with the LRG manure which contained 0.38% N (Table 3). It is likely that the difference in manure quantity and quality resulted in better yield for the HRG. The difference in yield was also probably a result of different management of the crops between the two farmer resource groups and the interaction of management with rainfall distribution.

In the first season both LRG and high HRG farmers planted at about the same time, by early December. All farms were similarly affected by the good December rainfall for plant establishment and the subsequent three-month dry spell which severely limited grain yield. By contrast, in the second season, farmers in the HRG tended to have planted by early December and those in the LRG by mid- to late-December. This difference in planting date resulted in beneficial and detrimental post-sowing rainfall conditions for the respective crops, culminating in some grain yield for the HRG crops in a severely below average rainfall season, and almost no yield for the LRG crops. Conversely, in the third season, the high resource farms mostly sowed their fields at the end of December 2003 and the growth of their crops coincided with 4 months of above average rainfall, whereas the low resource farms had mostly planted by early December, and experienced post-sowing moisture stress through December causing set-backs to crop growth. The low resource farms probably planted earlier in the third season because of the early planting benefits that they had seen in high resource farms during the second season. However, it appears the high resource farms based their planting decisions on other issues, probably weather forecasts from the radio; hence they planted at a more optimal time in all the three seasons.

Further management differences between the farmer resource groups were observed for weeding and fertilizer operations in the 3rd season as well. For example, the high resource farms tended to carry out weeding (av. 5 days) and fertilizer application (av. 12 days) earlier than the low resource group and this undoubtedly contributed to the much better crop yields achieved by the HRG in this particular season.

Performance of fertility treatments and farmer evaluations in each season

Season 1. Application of cattle manure alone produced maize grain yields of 0.18 and 0.44 t ha^{-1} for the 3 and 6 t ha^{-1} rates, respectively, in the first cropping season (Fig. 3). Addition of a small rate of N fertilizer as top dressing (8.6 kg N ha^{-1}) significantly increased grain yields to 0.32 and 0.62 t ha^{-1} ($P < 0.001$) at the two rates of manure application. This represents an 82% and 41% grain yield increase in a season with severe moisture stress. Grain yield did not differ significantly between manure application rates ($P = 0.075$), and there was no interaction between manure rates and fertilizer treatments. However, maize in the surrounding fields where no manure or fertilizer had been applied produced very little or no grain yield in this season.

The observed yield differences in the first season are largely explained in terms of the amount of N applied in the manure and fertilizer treatments (Fig. 4). The strong relationship ($R^2 = 0.77$) between yield and N applied suggests that the maize crops were highly responsive to N inputs, that the N applied had an agronomic use efficiency (AUE) of 18 kg grain per kg of N applied, and that manure-N was as readily available to the crops as the fertilizer-N. While the latter may be unexpected, it is probably related to the dry seasonal conditions such that crop demand for N was weak and readily met from the organic manure source.

Farmers evaluated the yield results at the end of the first season during the report back and planning meetings. Both groups of farmers agreed that the application of manure increased grain yield and the yield was even better when the crop was top dressed with nitrogen fertilizer. The farmers however said they needed to repeat the trials, but that they should include a control plot because it was not yet clear how good the technology was against a zero input comparison. It was also agreed that there was need to include the recommended fertilizer practice to see how it would compare with the manure treatments.

Season 2. The second season (2002–2003) was very dry (Fig. 1) and this resulted in poor maize grain yields, particularly in the LRG farms, which harvested very little grain (Fig. 5). Three out of eight farms in the LRG harvested grain yields ranging between 22 kg ha^{-1} and 93 kg ha^{-1} (< 50 kg ha^{-1} on average). Four out of seven farms in the HRG managed to harvest grain and the yields were slightly higher than the yields obtained from the 2001–2002 season. Due to the severe drought conditions, no fertility treatment produced a maize yield significantly greater ($P = 0.057$) than the control for either resource group. The average grain yield of the control plots in the HRG was 619 kg ha^{-1}, compared with 795 kg ha^{-1} (manure only), 905 kg ha^{-1} (manure + N) and 774 kg ha^{-1} (high D, high N) from the other treatments. The yield differences were related more to the activity calendars followed by the farmers during the season.

When the results were discussed with the farmers at the end of the season they all wanted to repeat the trials. However, the farmers also decided to vary the recommended fertilizer treatment to look at combinations of low and high rates of starter and top-dress fertilizers (Table 1).

Season 3. As reported earlier, with good rainfall (672 mm), the observed maize yields in the third season were considerably higher than the previous two drought-affected seasons (Fig. 6). This is seen in the high grain yields achieved for the control treatment (average 1.26 and 2.76 t ha^{-1}) of each resource group.

Application of manure alone at either 3 or 6 t ha^{-1}, produced significantly higher grain yields (1.96 and 3.44 t ha^{-1}, $P = 0.014$) compared with the control plots. As in the previous two seasons, top-dressing the manure with 25 kg ha^{-1} AN increased grain yields relative to manure alone, but this increase was statistically significant only for the HRG farms in this season. In the LRG, manure alone produced an average yield of 1.96 t ha^{-1} compared to 2.50 t ha^{-1} when AN was used as top dressing. In the HRG the manure only

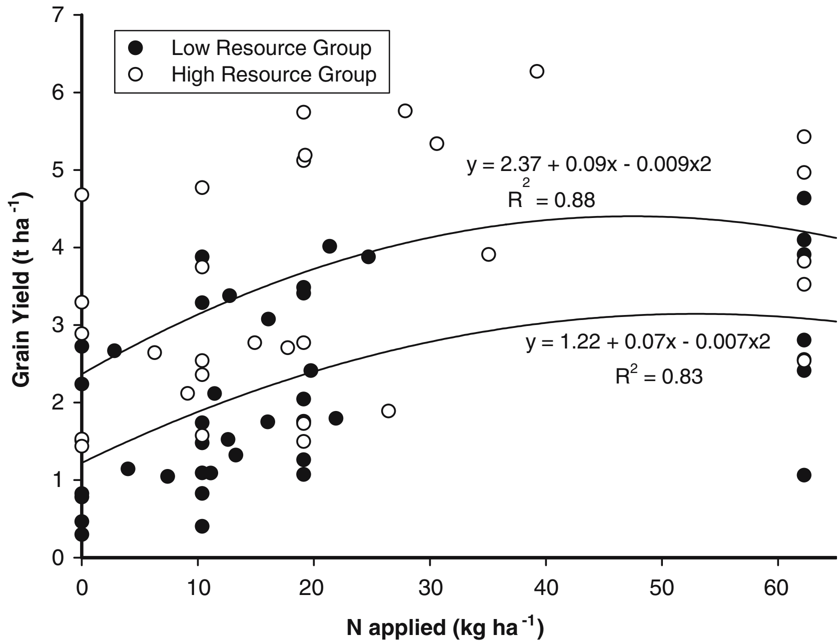

Fig. 7 Maize grain yield response to N applied, 2003–2004 season

treatment produced 3.44 t ha^{-1} while the manure + N treatment produced 4.28 t ha^{-1}. For both resource groups, yields with the recommended fertilizer treatment were not significantly greater than the yields achieved with the manure +AN treatment. As with the maize responses in season 1, the observed yield responses in the third season can be explained largely in terms of the amount of N applied in the manure and fertilizer treatments (Fig. 7). However, with the better rainfall and greater N inputs the overall relationship was stronger (R^2 = 0.88 for HRG and R^2 = 0.83 for LRG) reflecting the larger amounts of N applied in the third season compared with seasons 1 and 2.

It is striking that high yields in the third season were achieved with no inputs and the maize yields were consistently larger for farmers in the HRG (Fig. 7). An explanation for the good yields without inputs is probably the accumulation of N (and other nutrients) in the soil following the restricted crop uptake in the previous two dry seasons. For example, measured nitrate-N amounts in the surface 30 cm of soil at the start of the 2003–2004 season, although relatively small for both sets of farms (8–12 kg NO_3-N ha^{-1}), were nevertheless 2–3 times the amount measured at the start of the second cropping season in the same soil layer. The amounts of mineral N in the 0–30 cm soil layer at the start of this season relative to measured grain N of 32–45 kg ha^{-1} in the control treatments indicates that there must have been significant amounts of readily mineralizable organic N in the soil, or that nitrate-N accumulated below 30 cm, or a combination of these two conditions.

The consistently larger maize yields across all treatments for the HRG farmers is most probably related to the more favourable management factors of planting date, weeding and fertilizer applications as described earlier. In addition to the positive effects of management the HRG also benefited from the additional N content from the manure. The higher rate of manure probably improved the availability of other nutrients (base cations and micronutrients) and the soil physical properties. At the end of the third season focus group discussions were carried out to get farmer feedback. When the results were presented all the maize farmers confirmed that manure was a beneficial amendment in their cropping system. This contrasted to earlier findings of Ahmed et al. (1997) who found that 60% of farmers in the Tsholotsho district did not apply available manure to their fields because they perceived negative effects from using manure; low crop yields and increased weeds combined with constraints in applying manure to croplands. In our study farmers agreed that the application of ammonium nitrate as top dressing was a definite advantage, further increasing their maize grain yields. Farmers expressed satisfaction with the technology and they requested the researchers to source ammonium nitrate fertilizer in affordable small packs and make it available in their local trade stores. They confirmed that their neighbours had also copied the technology having observed the benefits during field days and they were also convinced that the manure/ammonium nitrate technology worked. The group asked if there were other technologies that they could move to because they had gained enough knowledge on manure and fertilizer over the three seasons.

Discussion

The participatory action research strategy demonstrated an interest by farmers in testing small doses of fertilizer N in combination with manure. The research remained within the resource capacity of the farmers, below the recommended rates that they could not afford. The process combined both research and adoption, a possible measure of the impact of the technologies. Continued evaluation of results with farmers led to the inclusion of large rates and combinations of small and large rates of fertilizer in comparison with the low rates of manure and fertilizer, therefore increasing options for the farmers. The process showed that there is a valid argument in encouraging research to focus on technologies that take into account farmer's constraints and improve farmer's capacity to adapt technologies to their own situations (Snapp et al. 2003; Dimes et al. 2004a, b).

Grain yield across the seasons was closely related to the rainfall amount and pattern as observed by researchers in other regions of Zimbabwe (Piha 1993; Piha et al. 1998). This is not surprising in this moisture-limited environment. With good rainfall, maize crops responded strongly to the application of the recommended fertilizer treatment, producing the greatest yield for the LRG farms (3.07 t ha^{-1}) and the second largest for the HRG farms (4.06 t ha^{-1}).

The yield results in the third season in Mkhubazi were however high for both resource groups compared with the reported average yields of less than 0.6 t ha^{-1} for cereal grain crops in Zimbabwe (Ahmed et al. 1997). The good yields were mostly explained by the combined response to nitrogen applied and available water from rainfall during the growing season. The application of small rates of starter (Compound D fertilizer) and top-dress fertilizer increased grain yield by an average of 0.40 t ha^{-1} compared with the control plots. Given the substantial increase in the amount of P added with the recommended Compound D treatment (21 kg P ha^{-1} compared to 3.5 kg P at the small rate of Compound D), the results suggest that the soils can supply the relatively small demand of P (and K) required to give these relatively small maize yields.

The calculated average agronomic nitrogen use efficiencies (AUE) were 53 and 31 kg grain per kg of N applied during the third season for the LRG and HRG farms, respectively. The third season was preceded by two dry seasons, therefore it can be concluded that the good N availability in the third season was due to the N applied, plus extra N probably accumulated in the soil during the previous two seasons. Our results clearly demonstrate that N is the major limiting nutrient on the Kalahari sands in this environment, but there are also clear interactions with other factors as demonstrated by the manure treatments. The AUE increased significantly for the manure only or manure + N fertilizer treatments. For the manure + N fertilizer treatment the AUE values were 58 and 72 kg grain per kg of N applied for the LRG and HRG farms, respectively. There is no clear explanation as to why the manures gave such remarkable AUEs compared with other fertilizers. Previous studies also showed strong responses to manure in Tsholotsho sands and Murwira et al. (2001) reported 2.5 t ha^{-1} maize yields when applying 3 and 6 t ha^{-1} of amended pit and heap treated manure. But they did not explain the responses in terms of nutrient supply. In high rainfall areas high responses to manure have also been reported (Murwira et al. 1998; Waddington and Karigwindi 2004). The results from this study have shown that the yield responses were probably not related to P effects, as the soils did not seem to be P limited. Studies carried out in the past attributed the manure effects to an increase in cation availability with manure in soils on granitic sands (Grant 1967). The benefits of manure providing other nutrients are probably also important in the Kalahari sands. In this uncertain rainfall environment the small N doses in combination with manure outperformed high doses of mineral N fertilizer across the three seasons. Similar benefits of N top-dressing with manure application have been found for maize production in Zimbabwe on granitic sands (Grant 1976; Thiessen 1979; Chikowo et al. 2004) and elsewhere in Africa (Carsky et al. 1998; Sherchan et al. 1999; Roose and Barthes 2001). Thus we confirm earlier findings that manure is a good substitute for basal fertilizer in this environment. Our results also indicate that the current blanket recommendations of 52.5 kg N ha^{-1} are inappropriate for the low rainfall regions and that future recommendations for fertilizers and manure should take into account the wide variability in potential yields.

The fact that grain yield across the seasons was closely related to the rainfall amount and pattern, raises more research questions. How often will the respective fertility responses be likely in this environment, and how can we anticipate such responses? These questions become more difficult as the maize responses were also influenced by management factors such as timing of sowing, fertilizer application and weeding, and that these varied with the two resource groups and also interacted with the rainfall pattern. Clearly, the three years of experimentation are inadequate in this regard but can provide the basis for further exploration of these interacting effects using modelling. The initial experiments (small amounts of manure and fertilizer) were the outcome of using a simulation model with farmers (Carberry et al. 2004), which suggested that under good management conditions small doses of fertilizer and manure would give reliable increases in productivity. The outcome of the experiments showed that the model predictions were reliable. There are food security benefits to farmers when manure and fertilizer are used in small rates. However, there is still need to model the results over a long period to see if the technologies are sustainable in the long run. We are currently testing the models' capability in reproducing the observed field responses under circumstances of different rainfall, soil and management conditions.

In conclusion the work has shown that low input technologies can work through the participation of smallholder farmers. Therefore, there is a need to continue exploring technologies that are targeted to the smallholder farmers, which have the potential to improve their food security.

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