SOIL WATER AND NUTRIENT MANAGEMENT FOR RAISING PRODUCTIVITY AND PROFITABILITY ON SMALL-SCALE FARMS IN DEGRADED LANDS OF SOUTHERN ZIMBABWE

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Abstract
This paper discusses the development of strategies to improve food sufficiency in communal farming lands of semi-arid southern Zimbabwe. Improved management is necessary to achieve the potential of improved crop cultivars. We used a participatory approach with emphasis on agronomy, socio-economic factors and technology exchange. Technologies, identified at farmer meetings, were evaluated on farmers' fields in Tsholotsho and Gwanda South. We tested post-planting or modified tied ridging for water conservation (with and without fertility inputs), methods and rates of manure (FYM), combined FYM and fertilizer, and small inputs of fertilizer. Most technologies increased yields, and farmers assessed them as practical and effective. Despite drought and externalities (e.g. economic conditions), there is adoption, particularly with water and fertility management options. We used modelling with APSIM to extend results to a greater range of seasons, and to promote engagement with farmers. It has also helped provide prior evaluation of technologies (e.g. weeding), and has also helped in demonstrating to farmers the importance of improved record keeping. Small inputs of fertilizer, FYM-fertilizer combinations, and adoptable methods of water retention proved to be good investment options. The combination of three research approaches – on-farm participatory trials, modelling, and farmer surveys – indicated successful adoption of technologies, and opportunities for further adoption. More male-headed households favoured small inputs of fertilizer and water harvesting, *de facto* female-headed households accepted heaped-covered composted FYM, FYM composted in pits, small inputs of fertilizer, and FYM-fertilizer combinations, and *de jure* female-headed households favoured heaped-covered composted FYM, and modified tied ridges. To help farmers invest, extension agents are recommended to escape from emphasis on ideal recommendations, and offer a basket of options. Extension services need to link to marketing to stimulate adoption of fertility technologies to generate income.

Introduction

One-third of southern Africa is semi-arid with low and declining soil fertility. In Zimbabwe, 55% of land is semi-arid, but has 63% of the rural population (Mapfumo and Giller 2001). These lands are officially recommended for semi-extensive and extensive farming, and have poor and erratic rainfall averaging 450-650 mm per year in agroecological region IV and <450 mm in region V, and distribution characterized by alternating spells of wet and dry weather in the rainy season (Department of Meteorological Services 1981), making it difficult for farmers to determine sowing dates (Scoones 1994). Here we report on strategies to improve food sufficiency while protecting and conserving the natural resource base. In the study areas in the southwest of Zimbabwe, the soils are mainly derived from felsic (gneissic) rocks, with some deep Kalahari sands, and some soils derived from mafic (basalt) rocks. Most of these soils are sandy and nitrogen (N) deficient, are of low fertility, having been degraded by cultivation and erosion. Grant (1981) reported on the poor potential of soils in these lands under continuous cultivation, and other publication supports this view. Prior to independence in 1980, the national system prioritised higher producing lands with commercial agriculture, and aimed at maximizing yields. In the 1980s, there were expanded on-farm adaptive trials and farming systems research in smallholder areas (Mashiringgwani 1980). Fertilizer trials tested the validity of earlier fertilizer recommendations, established nutrient response curves of crops that had received little attention, and developed ways of transferring fertilizer technologies to farmers. Since then few new technologies have been offered to farmers because research has become fragmented and separated from the overall research program (Hungwe and Murambadoro 1995). Consequently less than 10 percent of farmers apply fertilizer as recommended by extension agents, even when it was on credit – it has been too risky and giving too little return under low rainfall conditions (Singh 1995). Also available fertilizer compounds such as compound D are inflexible and poorly suited to soil and water conditions, supplying potassium and N in excess of crop needs. Recommendations have been further invalidated by recent high inflation. Our objective was to seek solutions to the issue of low yields, food insecurity and poverty in the communal areas. Here we examine (1) the results on on-farm testing of potential technologies, and (2) the idea of using systems modeling to increase the efficiency of on-farm studies. ICRISAT recognises that improved crop management is necessary to realise the benefits of improved cultivars. We used a participatory approach with an emphasis on agronomy, socio-economics and technology transfer. Potential technologies, identified at farmer meetings, were evaluated in combinations of researcher- and farmer-managed trials on farmers' fields at Tsholotsho and Gwanda South. The options tested were evaluated by researchers as yield, and by farmers using matrix scoring and ranking.

Materials and methods

On-farm testing

Tsholotsho (latitude 19 46 S, longitude 27 44 E, altitude 1090 m) receives an annual average rainfall of 650 mm, with soils including cambisols, luvisols, regosols and phaeozems (WRB) or haplustalfs, haplustolls, ustochrepts and ustopepts (Soil Taxonomy). Gwanda South (latitude 21 34 S, longitude 29 02 E, altitude 935 m) receives an annual average rainfall of about 500 mm, with soils including cambisols and luvisols (WRB) or ustochrepts and haplustalfs (Soil Taxonomy). Table 1 gives a weather summary in the two seasons 1999-2000 and 2000-2001.

Table 1. Weather summary for rainy seasons 1999/2001 at Tsholotsho and Gwanda South.

Location	Year	Month	Daily rad'n (mJ m^{-2})	Max temp (^oC)	Min temp (^oC)	Rain total (mm)
Tsholotsho	1999/2000	Dec-Mar	20.7	28.6	15.5	340
	2000/2001	Dec-Mar	19.8	26.6	15.3	590
Gwanda	1999/2000	Dec-Mar		29.1	19.4	1405
South	2000/2001	Dec-Mar		30.3	19.4	550

The four months of 01 December to 31 March approximate the growing season of sorghum. At Tsholotsho the 1999/2000 growing season rainfall was less than needed for a good crop, whereas the 2000/2001 growing season was mildly drought-affected. At Gwanda South, the 1999/2000 growing season rainfall was more than needed for a good crop, whereas the 2000-2001 season was a drought because of poor distribution.

Several technologies were tested and those reported here included:

- Modified tied ridging for water conservation, with and without fertilizer and FYM,
- Goat and cattle FYM by different composting methods to improve soil quality.

There were three methods of FYM composting. Water conservation management was tested by comparing tied ridges (made at time of first weeding) versus no tied ridges. The trials were chosen at meetings with farmers in which problem identification exercises resulted in a strong demand to look at ways to deal with low soil fertility, and a willingness of farmers to test manure as an input, with a request to test FYM and water management in combination.

Manure type and treatment (combined on-farm trial and simulations)

The example was on the farm of Mr and Mrs Johnson Nkomo in Gwanda South, where, on a site with a Chromi-Leptic Cambisol (WRB) or Lithic Ustochrept (Soil Taxonomy), we compared goat and cattle FYM, and evaluated the effects of 3 different pre-treatments, preparation by (1) the conventional method of storing the FYM in heaps which were not covered, (2) storing in heaps which were covered with a layer of soil, and (3) storing in a pit which was covered with a layer of soil. FYM was taken to the field and applied to the plots in December prior to seeding.

The experimental design was 2 manure types (cattle and goat), 2 rates of FYM (0 and 5 t ha^{-1}), 3 treatments of the FYM, and 2 replicates. The experiment and the surrounding area were sown by the farmer using sorghum (cv Macia) in 0.9 m rows which were later thinned to 0.25 m between plants within rows. All farm operations were by the farmer. At physiological maturity, the researchers and farmers harvested the experimental plots, and researchers determined grain yield for all treatments. Results were analysed by the appropriate statistical analysis methods. Farmers separately evaluated the experiments by field observation prior to harvest.

Since the researchers were constrained (by the donor) to two years of field trials, the systems simulation package APSIM (McCown et al. 1996) was used to simulate sorghum yield for 1990-2001. The outputs were compared with the performance of sorghum with different treatments, and used to assess the climatic risk of soil fertility inputs.

Water management with and without FYM and fertilizer - combined on-farm trials and simulation

The example reported was on the farm of Mr and Mrs Simeon Moyo in the Tsholotsho district, where, on a site with a Stagni-Vertic Luvisol (WRB) or Oxyaquic Haplustalf (Soil Taxonomy), we tested the effects of tied ridging for soil and water conservation, and evaluated the effects of 4 soil fertility pre-treatments, namely (1) no inputs, (2) input of N fertilizer at 18 kg N ha^{-1}, (3) input of 5 t ha^{-1} of FYM, and (4) input of both fertilizer and FYM. FYM and fertilizer were applied to the plots in December prior to sowing. The experimental design was 2 surface management treatments (traditional land preparation, and tied ridges), 4 soil fertility input combinations, and 2 replicates. The experiment and its surrounds were sown by the farmer using sorghum (cv Macia) in 0.9 m rows, later thinned to 0.25 m between plants within rows. Tied ridges were established by the farmer at the first weeding (as decided by the farmer) by use of the weeding implement to build the ridge, and hand tools to install the ties. All farming operations were conducted by the farmer. At physiological maturity, the researchers and farmers harvested the experimental plots, and researchers determined grain yield of all treatments. Results were analysed by appropriate statistical analysis methods. Farmers evaluated the plots by observations prior to harvest. Since the trials were constrained (by the donor) to two years, the simulation package APSIM (McCown et al. 1996) was used to simulate sorghum growth and yield for 1990-2001. Model inputs were obtained from weather station data, with soil characteristics from sampling and analysis at locations near trial sites. Outputs were compared with sorghum performance with different treatments, and used to assess climatic risk of soil fertility inputs.

Economic evaluation

Enterprise and whole-farm budgeting was used with @RISK for evaluation. An enterprise budget was constructed for each investment option, in this case sorghum, and different crop production technologies, including FYM, fertilizer and ridging. Budgets were constructed using yield and input-output coefficients obtained from farm survey data, on-farm experiments, and yields predicted by APSIM. Product values were obtained from government and farmer union sources, and input prices obtained from suppliers with transport prices added.

Results and discussion

On-farm studies with different manure sources and composting method

The trials comparing two sources of FYM and three methods of composting are shown in Table 2. These results are highly variable and the two years results offer no clear conclusion.

Table 2. Evaluation of cattle and goat FYM with different methods of preparation for sorghum grain yield (t ha^{-1}) on the Johnson Nkomo farm in Gwanda South, southern Zimbabwe.

		Goat			Cattle		
Season	No input	Heaped covered	Heaped uncovered	Pit	Heaped covered	Heaped uncovered	Pit
1999/00	1.54	1.97	1.58	1.50	3.27	2.26	1.46
2000/01	1.94	1.70	2.14	1.81	1.69	1.74	2.86

The results from APSIM simulations for the above two years were within the general range seen in the field, and for the longer period of 11 years were similar to the memories of the farmers. Thus we some confidence in the simulations of crop performance between 1999 and 2001 (Table 3). This indicates that without inputs, there were low yields and frequent crop failure. With added FYM, there were fewer crop failures, and generally about 50% higher yields, and both goat and cattle FYM were effective. Farmers' evaluations generally confirmed the suggestion that FYM had improved sorghum yield and that crops did not show signs of 'burning'.

On farm studies of water conservation, manure and fertilizer inputs

The trials evaluating tied ridging and combinations of FYM and fertilizer are shown in Table 4. There were suggestions of responses, but results were variable. Since the APSIM simulated yields were within the range of observed results, the simulations for an 11-year period were also tabulated (Table 5). The modeling indicated that without inputs, yields were low and there was high risk of crop failure. With added FYM, there were fewer crop failures, and about 50% higher yields. Both goat and cattle FYM were effective. Local farmers confirmed the idea that FYM had improved sorghum yield and that there was no 'burning'. We found the simulations to be a useful tool in discussions with farmers who were patient with our initially unimpressive efforts at simulating yields. Also the farmers recognized that they could benefit from improving the record keeping of their operations.

Risk-return tradeoffs of smallholder investments in relation to improved soil fertility management options

Tables 6-8 give the returns and risks above fixed costs for sorghum for the 11 seasons, 1990/1 to 2000/1, for alternative soil fertility inputs, and for three different household categories. For male-headed households, which are characterized by a resident husband, more labour and use of draft animals, the most profitable (least negative) technologies are sorghum grown with kraal manure plus modest inputs of N fertilizer, and modest amounts of N alone. The ranking is similar at both sites, but returns were higher at the wetter Tsholotsho site. For *de facto* female-headed households (absent husband – intermediate resource endowments, better access to off-farm cash), at the drier site, highest returns were from sorghum with kraal FYM plus modest inputs of N fertilizer, and with the lower input of N, whereas at the wetter site, highest returns were from sorghum with kraal FYM plus the higher rate of N, pit FYM, and the lower amount of N. For *de jure* female-headed households (the most resource-constrained group), returns are similar to those of the *de facto* female-headed households. For all household types at both sites, higher expected returns are associated with higher risks, and lower expected returns with lower risks.

Table 3. APSIM simulation of value of cattle and goat FYM with different methods of preparation for sorghum grain yield (t ha^{-1}) on the Johnson Nkomo farm in Gwanda South, southern Zimbabwe – means of treatment groupings.

Season	No inputs	Uncovered mean	Covered mean	Pit mean	Cattle mean	Goat mean
1990/91	2.89	2.93	2.94	2.92	2.92	2.95
1991/92	0.00	0.00	0.22	0.21	0.14	0.33
1992/93	0.00	0.34	0.41	0.08	0.05	0.38
1993/94	0.00	0.42	0.72	0.63	0.62	0.41
1994/95	0.00	1.53	0.58	0.13	0.90	0.49
1995/96	2.34	0.69	1.04	1.59	0.46	1.47
1996/97	0.00	0.60	0.69	0.30	0.12	0.71
1997/98	0.00	0.69	0.00	0.32	0.67	0.00
1998/99	0.00	0.36	1.20	0.25	0.73	1.20
1999/00	0.53	0.00	0.16	0.00	0.11	0.97
2000/01	0.00	2.09	1.62	0.36	1.31	1.43
Mean	0.52	0.88	0.87	0.62	0.73	0.94
Failures per 11 yrs	7	2	1	1	0	1

Table 4. Evaluation of tied ridges, cattle FYM and fertilizer for sorghum grain yield (t ha^{-1}) on the Simeon Moyo farm near Tsholotsho, southern Zimbabwe.

Season	Treatments	No input	FYM only	N fert only	FYM + N	Mean
1999/2000	Flat	2.39	1.79	3.09	3.39	2.67 ns
	Tied ridges	1.51	2.19	2.77	3.12	2.40 ns
	Mean	1.95 a	1.99 ab	2.93 ab	3.26 b	
2000/01	Flat	1.60	2.68	1.97	2.34	2.15 ns
	Tied ridges	1.23	2.23	1.91	2.03	1.85 ns
	Mean	1.41 a	2.45 b	1.94 ab	2.18 ab	

Table 5. APSIM simulation of value of conventional flat cultivation versus tied ridging, together with testing inputs of fertilizer, FYM, and combined fertilizer and FYM for sorghum grain yield (t ha^{-1}) on the Simeon Moyo farm near Tsholotsho, southern Zimbabwe – means of treatment groupings.

Season	No input mean[1]	Fertilizer mean	FYM mean	Fertilizer + FYM mean	Flat cultiv'n mean[2]	Tied ridging mean
1990/91	2.71	2.86	2.90	3.55	3.08	2.94
1991/92	0.00	0.69	0.00	1.16	0.46	0.47
1992/93	0.00	0.24	1.18	0.36	0.47	0.43
1993/94	0.00	0.34	0.49	0.77	0.41	0.40
1994/95	0.00	0.53	0.64	1.84	0.60	0.91
1995/96	1.31	0.93	2.41	2.11	2.17	1.22
1996/97	0.13	0.53	0.41	0.90	0.45	0.57
1997/98	0.29	0.98	0.41	2.26	1.09	0.92
1998/99	0.00	0.56	0.77	1.73	0.20	0.83
1999/00	0.37	1.10	0.19	2.31	1.07	0.92
2000/01	0.00	0.60	0.60	0.72	0.41	0.55
Mean	0.44	0.85	0.91	1.20	0.94	0.92
Failures per 11 yrs	6	0	1	0	0	0

[1] Columns 2-5 are each means of flat cultivation and tied ridging treatments; [2] columns 6 and 7 are each means for the four soil fertility treatments.

Surveys show that most farmers prefer maize even where environmental conditions favour sorghum and pearl millet. They grow some sorghum and pearl millet to diversify risk and as insurance against complete loss of crop in a poor season. Two-thirds of households face regular food deficits because of high incidence of crop loss. Further simulation modelling has suggested that small inputs of inorganic fertilizer, composted FYM, and FYM-fertilizer combinations have potential for the *de facto* female-headed households with access to cash, legume rotations in the male-headed households with access to draft animals, labour and land, and small inputs of inorganic fertilizer and legume intercrops in the *de jure* female-headed households who have resource constraints.

Table 6. Expected returns and risk (Zimbabwe $ ha^{-1}) of sorghum soil fertility management technologies for male-headed households (i.e. higher endowments) in Gwanda South and Tsholotsho, 1990/1-2000/1.

	Gwanda South		**Tsholotsho**	
Activity	**Return**	**Risk**	**Return**	**Risk**
Sorghum + kraal FYM	-15272	3948	-13793	5310
Sorghum	-2440	4350	-156	6347
Sorghum + 9 N	-849	5856	1911	7642
Sorghum + pit FYM	-1888	6752	542	8752
Sorghum + 18 N	-2330	7703	788	9718
Sorghum + kraal FYM + 18 N	-154	7759	3314	10160
Sorghum + kraal FYM + 9 N	-450	9765	2711	11107

Table 7. Expected annual returns and risk (Zimbabwe $ ha^{-1}) of alternative sorghum soil fertility management strategies for *de facto* female-headed households (i.e. absentee husband repatriating funds), Gwanda South and Tsholotsho, 1990/1-2000/1.

	Gwanda South		**Tsholotsho**	
Activity	**Return**	**Risk**	**Return**	**Risk**
Sorghum + kraal FYM	-12801	3654	-10128	4911
Sorghum	62	4366	3177	6334
Sorghum + 9 N	2203	6042	4874	7642
Sorghum + pit FYM	344	6435	4908	8839
Sorghum + 18 N	697	7863	3548	9749
Sorghum + kraal FYM + 18 N	2873	7911	6205	10293
Sorghum + kraal FYM + 9 N	2577	9980	3890	8759

Table 8. Expected annual returns and risk (Zimbabwe $ ha^{-1}) of alternative sorghum soil fertility management strategies for *de jure* female-headed households (i.e. no husband, most resource-constrained), Gwanda South and Tsholotsho, 1990/1-2000/1.

	Gwanda South		**Tsholotsho**	
Activity	**Return**	**Risk**	**Return**	**Risk**
Sorghum + kraal FYM	-13023	3668	-7821	4410
Sorghum	1704	8129	5419	6018
Sorghum + 9 N	1981	5994	7181	7347
Sorghum + pit FYM	122	6398	6405	8531
Sorghum + 18 N	475	7814	5855	9464
Sorghum + kraal FYM + 18 N	2650	7861	8512	9992
Sorghum + kraal FYM + 9 N	2355	9926	6197	8470

Surveys of farmers in and around the trial sites have provided information about farmers' knowledge and adoption of technologies (Table 9). This indicated that about three-quarters of those who hosted trials were adopting some technologies from trial sites, and about half of farmers who were not hosting trials were adopting some ideas from trial plots. The most popular practices included new varieties, heaped and covered FYM, pit-composted manure, and modified tied ridges. Farmers reported that the constraints to greater adoption of such technologies were shortage of labour for making modified tied ridges, erratic rainfall and drought, cost of fertilizer, lack of animals for draft and transportation, 'burning' of crops by FYM, insufficient FYM, and lack of knowledge. Farmers also indicated need to improve input and output markets for cash returns for further investment in productivity.

Table 9. Farmers' knowledge of new practices, adoption of practices, and reason for not using FYM and inorganic fertilizer, Tsholotsho and Gwanda South (% of respondents).

	1998/99		2002/03	
	Gwanda Sth	**Tsholotsho**	**Gwanda Sth**	**Tsholotsho**
Changes in farmers' knowledge and practice				
Know FYM	Na	na	98	99
Know inorganic fertilizer	Na	na	98	99
Know tied ridges	Na	na	76	75
Used FYM in survey year	3	20	20	15
Used inorganic fertilizer in survey year	3	9	5	36
Used tied ridges in survey year	1	1	21	29
Reasons for not using FYM				
Burns the crop	62	7	20	2
No perceived benefits	22	40	15	24
Lack of transport	3	19	1	7
Lack of labour	0	0	3	13
Low rainfall	0	0	31	13
Reason for not using inorganic fertilizer				
Too expensive, risky	45	19	31	22
Fertilizer not needed on my soils	12	11	6	0
Lack of cash to purchase	9	36	17	36
Fertilizer not available	8	22	14	22
Burns the crop	8	2	12	4

Conclusions

Declining soil fertility, and low and erratic rainfall are major constraints to increasing productivity in smallholder farming systems in the communal farming areas of southern Zimbabwe. There is a need for improved soil water and nutrient management. Small quantities of inorganic fertilizer, manure-fertilizer combinations, and adoptable methods of water retention are good investment opportunities, especially in higher rainfall areas. A combination of three research approaches – on-farm participatory research trials, simulation modeling, and farmer surveys – has indicated successful adoption of technologies, and opportunities for further adoption. Proportionately more male-headed households favour legume rotations, small quantities of fertilizer and water harvesting, de facto female-headed households accept heaped-covered composted FYM, FYM composted in pits, small quantities of inorganic fertilizer, and FYM-fertilizer combinations, and de jure female-headed households favour heaped-covered composted FYM, and modified tied ridges. We have demonstrated that differently resourced households will invest in technologies. To help with such investment, changes are needed in extension. Extension agents need to escape from the emphasis on ideal recommendations, and move to offering a basket of options. Extension services need to link to marketing to help stimulate adoption of fertility technologies that will generate cash. Legume crops will improve soil, are potentially marketable, and provide incentives for farmers to adopt soil and water technologies.

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