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Resource flows, crops and soil fertility management in smallholder farming systems in semi-arid Zimbabwe

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Abstract

Poor soil fertility and erratic rains are major constraints to crop production in semi-arid environments. In the smallholder farming systems of sub-Saharan Africa, these constraints are manifested in frequent crop failures and endemic food insecurity. We characterized a semi-arid smallholder farming system in south-western Zimbabwe to assess crop production, nutrient use and factors that constrain productivity. The farming system was studied using resource flow mapping, farmer interviews and calculations of crop production over three cropping seasons (2002/2003, 2003/2004 and 2004/2005) to capture variability between years. Farmers were categorized into three groups: better resourced, medium resourced and poorly resourced. Better resourced farmers produced adequate grain for basic household consumption, except in the drought year (2002/2003). Poorly resourced farmers had large grain deficits, whereas the medium resourced class had smaller deficits. Better resourced and medium resourced farmers produced adequate amounts of staple cereal in two of the seasons, while poorly resourced farmers produced inadequate amounts of food in all three seasons. All farmers produced less than 300 kg/ha of legumes per season. Lack of seed was cited as the main reason for poor legume production. Better resourced farmers used animal manure (2000–5000 kg per season) and some fertilizer on their cereal crops, while the medium resourced group used less manure (1000 kg or less) and no fertilizer. The use of manure varied strongly across the years. Poorly resourced farmers used no nutrient inputs on any of their crops. All groups had negative nitrogen balances during the three cropping seasons, although the values varied strongly between seasons. Investigation of the potential strategies for developing sustainable production systems are required to address the problems of food security in the semi-arid parts of the country and the region.

Keywords: Grain legumes, food availability, manure, resource flow

Introduction

Smallholder farming systems in Africa are faced with poor crop production and perennial food insecurity, especially in the semi-arid tropics where the majority of smallholder farmers live (Ryan & Spencer, 2001). Concomitant with poor rainfall, a major constraint to crop production is poor soil fertility, caused by inherently poor soil quality and inappropriate soil management practices (Sanchez, 2002; Vanlauwe *et al*., 2003). Throughout Africa, negative nutrient balances for nitrogen and phosphorus have been found in smallholder farming systems (Roy *et al*., 2003).

A thorough understanding of farming systems is required in order to develop appropriate technological interventions to manage soil fertility (Hilhorst & Muchena, 2000). Some studies have been conducted to assess the dynamics (including nutrient management and resource allocation) of smallholder farming systems (Defoer *et al*., 1998; Briggs & Twomlow, 2002; Tittonell *et al*., 2005b; Zingore *et al*., 2007). However, most studies have been conducted in medium to high rainfall areas. The few studies conducted in the semi-arid regions of Africa were carried out in West Africa close to large urban populations with strong market drivers (Harris, 1998, 2002). Data on resource allocation and use

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patterns in the semi-arid regions of southern Africa is limited to a few case studies (Scoones, 1997, 2001), and data on how farmers in the semi-arid regions cope with poor soil fertility are lacking.

Different resource allocation strategies of smallholder farmers have resulted in soil fertility gradients between farms and fields. In western Kenya, soil fertility gradients were found to be related to the variation in biophysical and socio-economic conditions (Tittonell *et al.*, 2005a) at the region and farm scale levels, whereas within-farm variability was related to differential resource allocation (Tittonell *et al.*, 2005b). In the higher rainfall conditions of eastern Zimbabwe, soil fertility gradients were a function of organic matter management (Mtambanengwe & Mapfumo, 2005) and concentration of nutrients such as fertilizer and manure in fields closer to homesteads (Zingore *et al.*, 2007).

Surveys and reviews on soil fertility management in the semi-arid regions of Zimbabwe have reported that there is a crisis in soil fertility management in the semi-arid smallholder farming areas (Mapfumo & Giller, 2001; Twomlow & Ncube, 2001). These authors highlighted the lack of quantitative information on indigenous soil fertility management practices, including nutrient balances in the semi-arid areas. There was also limited use of soil-improving nutrient sources, such as manure and fertilizer, mainly due to scarcity and high cost, respectively (Ahmed *et al.*, 1997). Crop rotations were limited and farmers were using crop sequences that were not designed to improve soil fertility. Few legumes were grown and they received the least inputs (Mapfumo & Giller, 2001; Twomlow, 2004). The reasons why semi-arid farmers follow such farming practices are not clear. There is therefore a strong need to characterize resource flows in smallholder farms in semi-arid regions, quantify crop productivity and nutrient balances and assess the factors limiting production (Mapfumo & Giller, 2001).

The district of Tsholotsho (Mkhubazi) was selected as representative of the extensive, mixed farming systems of south-western Zimbabwe based on findings of both traditional socio-economic household surveys (Ahmed *et al.*, 1997; Rohrbach, 2001) and more innovative participatory approaches (Carberry *et al.*, 2004) in the area. The farming in this district is also similar to the farming of eastern Botswana and southern Zambia. This earlier research in Tsholotsho has followed two complementary paths. Path one is a series of farmer participatory experiments using maize/manure and legumes to assess the feasibility of some of the soil fertility management strategies identified through farmer/researcher interactions. Path two consists of in-depth case studies of smallholder households cropping systems of varying resource status to identify resource allocation, productivity and soil fertility management strategies and comparing the results with the more crop- and market-intensive Zimbabwe sub-humid scenarios where possible. Results of the maize/manure experiments have been reported separately as Ncube *et al.* (2007). This paper reports the results of the case studies over three cropping seasons at Mkhubazi. The specific objectives of the studies were to: (i) categorize the farmers and characterize their farming system using resource flow maps, (ii) assess the current annual crop production, (iii) identify current soil fertility management strategies and (iv) identify soil fertility constraints within the farming system.

Methodology

The study site

The research was conducted at Mkhubazi village, Tsholotsho (27°41′E, 19°38′S), ward 13. Figure 1 shows the location of Tsholotsho District, wards 12 and 13, where soil fertility management experiments were conducted, and Mkhubazi Village.

The long-term (50-year) average rainfall for Tsholotsho is 590 mm per annum (Figure 2), falling mainly between October and May each year in a distinct wet season. The study area is dominated by deep (> 150 cm) Kalahari sands (Ferralic Arenosols; IUSS Working Group WRB, 2006) derived from aeolian sand parent material (Moyo, 2001). The soil type is locally referred to as *ihlabathi*, a term used to describe sand. There are also some small patches of Aridic Arenosols (*iphane*) and fields where *ihlabathi–iphane* are mixed. *Iphane* is a term used to describe the type of vegetation associated with the soils, Mopani (*Colophorspemum mopane*) trees in this case.

Zimbabwe is divided into five agroecological regions, also known as Natural Regions I–V. Natural Regions I and II receive the highest rainfall (at least 750 mm per annum) and are suitable for intensive farming. Natural Region III receives moderate rainfall (650–800 mm per annum) and Natural Regions IV and V have fairly low annual rainfall (450–650 mm per annum) and are suitable for extensive farming (adapted from Vincent & Thomas, 1960). Agricultural activity in Mkhubazi is typical of Natural Farming Region IV, primarily a semi-extensive mixed farming system, involving goat and cattle production, and cultivation of drought-resistant crops. Fields are individually owned, following allocation by the local headman. Access to land is not an issue and new fields are still being opened.

The major field crops grown are maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R.Br.) and groundnut (*Arachis hypogaea* L.). Minor crops include cowpea (*Vigna unguiculata* (L.) Walp), Bambara groundnut (*Vigna subterranea* (L.) Verdc), sunflower (*Helianthus annuus* L.) and cotton (*Gossypium hirsutum* L.). Melons (*Citrullus lanatus* (Thunb)) and pumpkins (*Cucurbita maxima* L.) are intercropped with cereals. Current extension service crop yield estimates are 0.40 t/ha (cowpea), 0.5 t/ha (pearl millet), 0.70 t/ha (sorghum) and 0.80 t/ha (maize) in a normal rainy season (District Agricultural Extension Officer, 2005). National average yields for

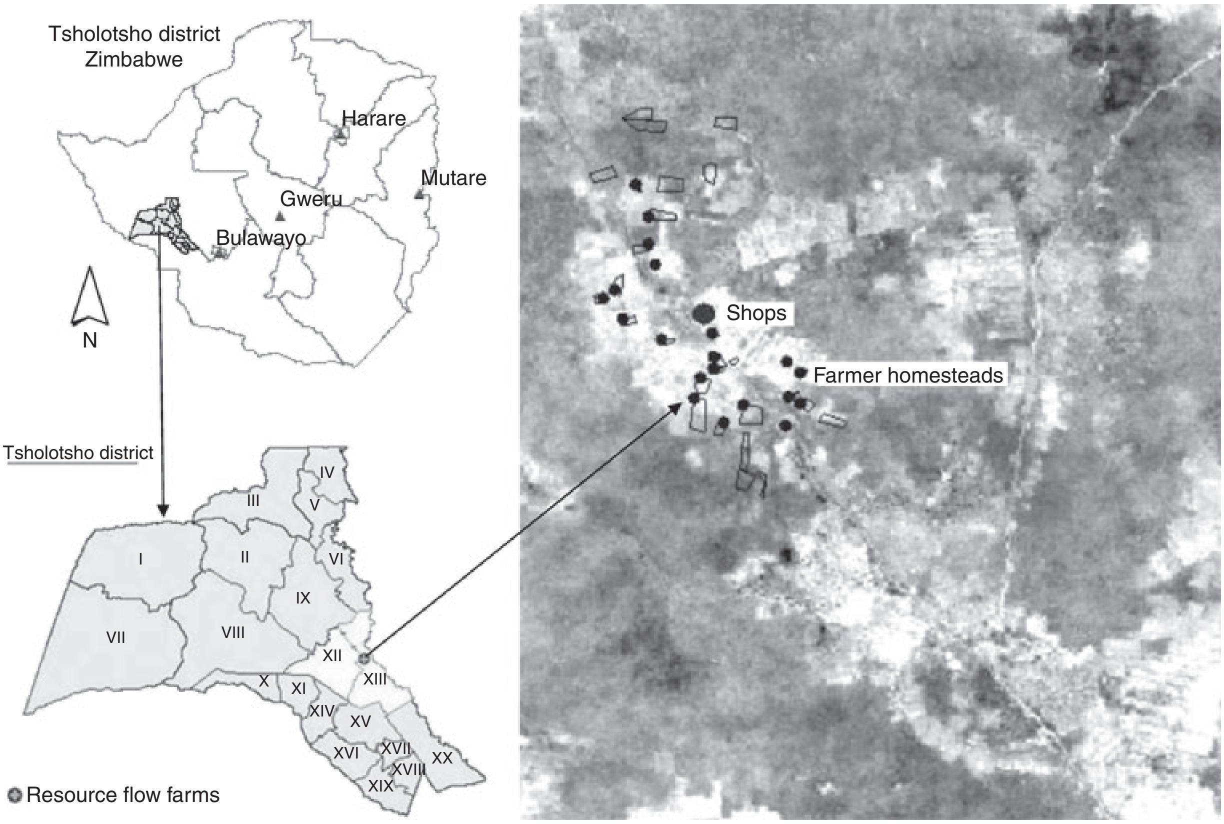

Figure 1 Location of Tsholotsho District, research wards 12 (XII) and 13 (XIII), and Mkhubazi Village. The black circles represent resource flow farms (homesteads) and boxes represent the fields. The whiter patches show fields and the darker areas represent forests. Map drawn by ICRISAT-Bulawayo GIS Unit, 2006.

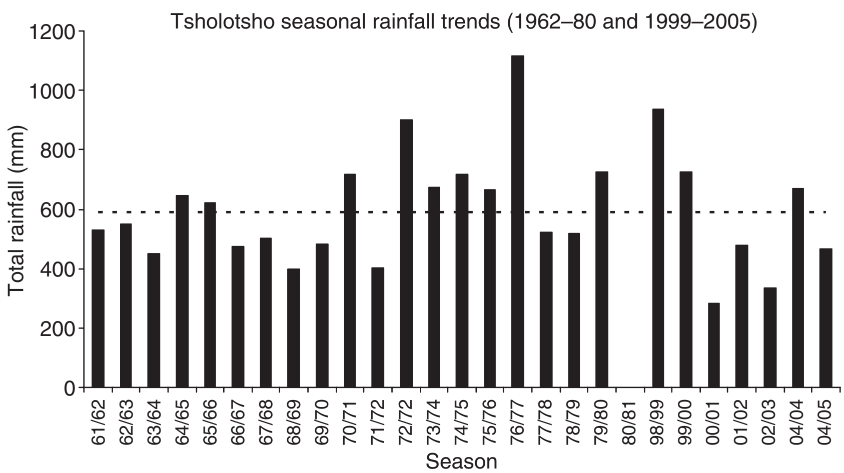

Figure 2 Seasonal (October to May) rainfall trends in Tsholotsho, Zimbabwe, between 1962 and 1980 and 1999 and 2005. The dashed line represents the long-term average (50 years) rainfall (590 mm). The data for the period 1981–1998 was missing from the Tsholotsho weather station records.

smallholder farming areas are 0.30 t/ha for both cowpea and groundnut and 0.6 t/ha for cereals (Hilderbrand, 1996; Ahmed *et al.*, 1997; Nhamo *et al.*, 2003).

Livestock production includes rearing of cattle, goats and donkeys. The livestock census of 2005 reported the following numbers in Mkhubazi: beef cattle (3150), goats (3829), donkeys (1509) and sheep (15) (District Agricultural Extension Officer, 2005). Livestock management involves communal grazing in the natural grazing lands during the day and housing overnight in kraals during the crop production period. Communal grazing in cropped fields is allowed after harvesting and during the dry season.

The farmers

Twenty farmers were selected for resource flow mapping. A list of all the farmers in the village was obtained from the village headman and a discussion was undertaken to clarify different household wealth categories in the village. The main criteria of classification used by the headman were livestock ownership and farming activities. He was then asked to classify the villagers into three broad groups (better resourced, medium resourced and poorly resourced). The groups were based on livestock and physical assets (ploughs, scotch carts and wheelbarrows) – mentioned by farmers as the most important criteria in preliminary discussions and resource flow mapping exercises conducted in the 2001/2002 season (Carberry *et al.*, 2004). A random subset of farmers was selected from each class (seven better resourced farmers, six medium resourced and seven poorly resourced farmers).

Resource flow mapping

The resource flow mapping methods used in the study were adapted from the approaches outlined by Defoer (2002) and Esilaba *et al.* (2005). The basic principles of developing a flow map were followed as outlined by the two authors, except that the delineations of the farms into crop production system (CPS), the animal production system (APS) and the household system (HHS) were omitted in analysing nutrient flows. Instead the farms were treated as single units. Flow maps were drawn during the cropping season for each household on four occasions starting with the 2001/2002 cropping season, although the first session was mainly to collect preliminary data. Each farm was visited in the middle of the cropping season to assess and discuss the various activities within the farm. Information collected covered issues such as the family structure, household map, ownership of livestock and farm implements, field map, farming objectives, cropping pattern (including estimates of area cultivated that were confirmed through field visits) and strategies used for soil fertility management.

During the mapping exercise each farmer drew his/her household and a field map on the ground showing where the various components of the farm were and where the various crops had been grown. The map was then transferred to a large sheet of paper and the seed source, nutrients applied and harvested yield from each crop was included to depict the various nutrient and resource flows within the farm. The farm was then toured with the farmer to confirm the various aspects shown on the map. Soil samples were collected from the farms (0- to 30 cm soil depth) to assess background nutrient levels in fields previously planted with cereals. Organic carbon, total N, total and available P and pH were analysed using the methods outlined by Okalebo *et al.* (1993), while nitrate-N was determined using the colorimetric method of Anderson & Ingram (1993). In season 1, the location of each household, the fields and their extent were determined using a calibrated hand-held global positioning (GPS) instrument. The instrument was first used to locate known benchmark sites such as the Tsholotsho weather station, and the results were found to be accurate, therefore it was used in the field with a high level of confidence.

During the visits, other aspects of the farming system such as problems of acquiring resources, selling harvests to the markets and food insecurity were noted each season. The role of legumes within the cropping system and the problems faced in growing them were discussed with each farmer.

Statistical analysis

Data on livestock and implement ownership, family size, crop yields and manure production were tested for significance using the Genstat 8.1 statistical package (GenStat, 2005). Standard errors of means of the farmer groups are presented.

Results and discussion

Soil chemical characteristics

Average soil chemical characteristics of farms from Mkhubazi are shown in Table 1. Soils samples (0–30 cm) were taken from different cereal fields each season. Cereal fields removed bias introduced by legumes and nutrients applied in the previous year. The soils were generally poor in organic carbon, available N (nitrate) and P (Olsen) and pH was low. The home fields and main fields did not show any significant differences in chemical characteristics in contrast to studies in higher rainfall areas in eastern Zimbabwe and other semi-arid cropping systems in sub-Saharan Africa (Scoones, 2001; Mtambanengwe & Mapfumo, 2005; Tittonell *et al.*, 2005a,b; Giller *et al.*, 2006; Zingore *et al.*, 2007).

Rainfall

Smallholders in the semi-arid environments are highly dependent on seasonal rainfall (Twomlow *et al.*, 2006). The Tsholotsho area has unimodal rainfall or crop growing season in which rainfall occurs from late October to March/April. An analysis of Tsholotsho's long-term rainfall trends from the 1960s to 2005 shows that amounts are generally low and inconsistent across seasons (Figure 2). The frequency of

Table 1 Soil characteristics of fields measured across three cropping seasons (2002–2005) at Mkhubazi, Tsholotsho District, Zimbabwe

Season	Field type	Soil type	PH	C (%)	Total *N* (%)	Nitrate *n* (p.p.m.)	Total P (%)	Olsen P (p.p.m.)
2002/2003	Home	Sandy	4.7	0.32	0.03	0.9	0.005	0.04
	Main	Sandy	4.9	0.38	0.03	0.6	0.01	0.07
2003/2004	Home	Sandy	5.8	0.31	0.05	2.2	0.01	0.02
	Main	Sandy	5.1	0.37	0.04	3.9	0.004	0.06
2004/2005	Home	Sandy	4.8	0.26	0.06	2.7	0.02	0.09
	Main	Sandy	5.0	0.2	0.02	2.0	0.01	0.17

meteorological drought is estimated once in every 13–19 years in Zimbabwe (Scoones, 2001) and the semi-arid regions are probably more affected. Poor within season distribution of the rainfall is another challenge that the farmers face. Tsholotsho is prone to mid-season dry spells in January that affects most of southern Zimbabwe. The dry spell is characterized by 14- to 21-day periods of no rainfall resulting in crops in the fields drying before maturity. Figure 3 shows seasonal cumulative rainfall measured across the 3 years of the study.

The 2002/2003 season was very dry (330 mm) and far below the long-term average of 590 mm. This was followed by above-average rainfall in 2003/2004 of 670 mm, and a drier (470 mm) than average season in 2004/2005.

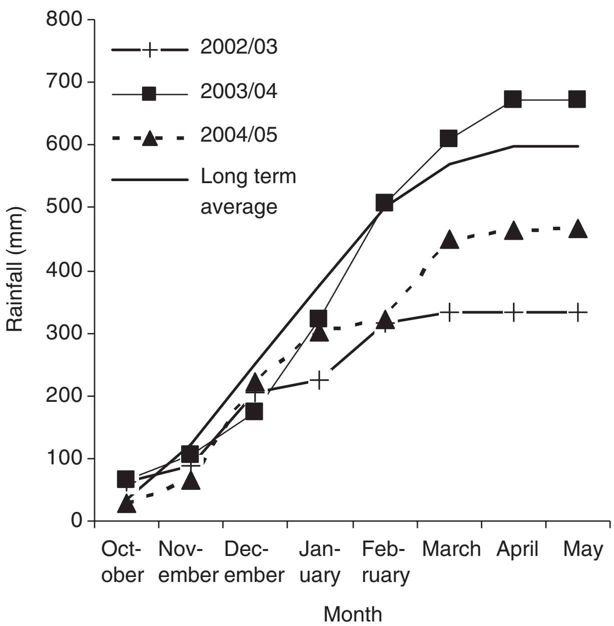

Figure 3 Cumulative monthly rainfall for three cropping seasons (2002–2005) in Tsholotsho, Zimbabwe. The solid line shows the 50-year long-term average. Only rainfall for the cropping season is shown as little or no rainfall falls during the dry winter season from April to November.

Resource flow mapping and resource allocation

Farmer classes. Table 2 shows farmer resource classes, livestock numbers and major asset ownership and the average size of the family within each category. Household sizes were larger in Mkhubazi than in the eastern parts of the country. The better resourced farmers had larger families than the other two classes but a smaller proportion of their families worked on the farms. The better resourced farmer class hired additional labour (on average, one person during the growing season).

Most farmers in the study area owned more than 3.5 ha of land; a contrast with farmers from the eastern part of the country where the largest farms were 3 ha in size (Mtambanengwe & Mapfumo, 2005; Zingore *et al.*, 2007). Most

Table 2 Farmer resource classes at Mkhubazi, Tsholotsho, Zimbabwe

	Farmer wealth class		
Criteria	Better resourced (*n* = 7)	Medium resourced (*n* = 6)	Poorly resourced (*n* = 7)
Land			
Average crop area (ha)	5.1 (0.7)	4.5 (0.7)	3.5 (0.8)
Livestock			
Cattle	7 (1.1)	2 (0.8)	0 (0.1)
Donkeys	3 (1.1)	3 (1.1)	0 (0.2)
Goats	15 (4.2)	12 (4.1)	2 (1 .0)
Chickens	29 (3.2)	13 (3.0)	4 (1 .6)
Assets			
Plough	2 (0.2)	1 (0.2)	0 (0.2)
Scotch cart (donkey drawn cart)	1 (0.2)	1 (0.2)	0 (0.1)
Wheelbarrow	1 (0.2)	1 (0.2)	0 (0.1)
Bicycle	2 (0.2)	1 (0.2)	0 (0.7)
Family size	9 (0.8)	7 (0.9)	6 (0.8)

The numbers in brackets indicate standard errors of means. Family size includes adults and children. Livestock numbers are average numbers recorded during the 2002/2003 season.

households had two land holdings, a homestead plot with a small cropped area, and a larger contiguous cropped area. Better resourced farmers owned the largest fields, up to 8.4 ha in size.

The largest number of livestock owned by better resourced farmers was 11 cattle, slightly more than recorded by Chibudu *et al*. (2001) in Chivi another semi-arid area that is more populous (average eight head of cattle). The average number of cattle in the better resourced group reported by Zingore *et al*. (2007) in Murewa east of Zimbabwe was 10–16, whereas the medium resourced owned two to nine head of cattle. Interestingly, Tsholotsho farmers owned much larger numbers of goats and chickens than farmers in the eastern parts of the country. The better resourced households in Tsholotsho owned enough cattle and donkeys to allow two ploughs to operate concurrently. The typical animal mouldboard plough is a VS200 pulled by a team of either two oxen or two donkeys. If donkeys are used, the animals are rotated every 1–2 h of work. Therefore, the better resourced group had no constraints of draught power for both farming and carrying manure. The medium-resourced class owned at least two head of cattle and some donkeys, and they also owned at least a plough and a cart. The poorly resourced farmers had many constraints. They had no cattle and donkeys, and did not own implements such as the plough and cart. Therefore, some of these farmers resorted to minimum tillage using hand hoes, whereas others shared draught animals with extended family members or neighbours. Consequently, the poorly resourced farmers left a greater proportion of their land fallow, especially during drier seasons. Some fields were abandoned during our study, probably because of low fertility and lack of labour. In wet seasons, poorly resourced farmers faced increasing labour constraints for weeding.

Resource flows. Figure 4 shows representative resource flow maps of the three farmer classes for an average rainy season (about 500 mm) relative to the homestead plot and the family dwellings. A hut is a round grass thatched room with walls of mud or brick and a thatched roof, while houses are normally roofed using corrugated iron or asbestos sheets. Grass for thatching can be obtained by all farmer classes but other materials have to be purchased in the cities. The total field areas do not add up to the averages for each resource class because all classes leave some land fallow every season, mainly because of labour and capital constraints and at times due to soil moisture limitations.

Figure 4a represents the better resourced farmer class. The yields shown in brackets are averages of the yields obtained across the three cropping seasons. About 60% of the cropped area was planted with millet annually, about 30% planted with maize and sorghum and the remaining 10% planted with groundnut and Bambara groundnut. Cowpea was planted as an intercrop in the sorghum and maize crop cycle. Cereal seed was purchased from every year. Legume seed was retained. Available animal manure was concentrated on the fields for maize. Better resourced farmers purchased small amounts of fertilizer, especially during good rainy seasons, although rarely more than 17 kg N per hectare per year. The farmers also applied ash and chicken manure to fields that were closest to the homestead. Each harvest was retained for household consumption, with surpluses sold only during the following cropping season if it promised to be good. However, pearl millet, which is less prone to storage losses than maize and sorghum, is often kept for up to two seasons as a longer term food reserve.

The medium resourced farm situation is depicted in Figure 4b. The farmers planted about 90% of the land with cereals [60% millet, 20% maize (1 ha) and 10% sorghum (0.5 ha)]. The remainder was planted with legumes, mainly groundnut. Seed purchasing patterns were similar to those for the better resourced households. The better resourced and medium resourced farmers also tried to earn income by planting cash crops such as cotton, although not in all seasons. Over the three seasons, a few farmers grew cotton and sunflower for sale, but at the end of the mapping period in 2004/2005 no farmer was growing cotton due to high input costs and low selling prices. The medium resourced farmers also used manure but at much lower rates (maximum 1000 kg per farm per season), than the better resourced farmers (average 5000 kg per season per farm). Ash was also applied to field portions nearest to the homestead. All harvest was kept for home consumption, except where cash crops were grown.

Figure 4c shows a poorly resourced farm with fewer flows, which are also smaller in magnitude compared with the medium and better resourced farmers. A large proportion (>40%) of land remained fallow (2 ha of 3.5 ha cropped) each season. Almost all the annual crop area was planted with cereals, mostly received through an emergency relief initiative facilitated by humanitarian relief agencies. A very small portion of land was planted with groundnut (<1% 0.01 ha in 2 ha) for which seed was obtained from neighbours. Poorly resourced farmers generally did not apply nutrients to their fields, except for ash applied to the home fields.

The distance of the field from the homestead was not a critical issue in the Mkhubazi farming system; farmers planted major food crops even in the farthest fields (up to 3 km away). Home fields were mainly used for growing maize and some legumes, which were eaten green, whereas the major grain crop (millet) was always planted in the main field.

The area planted with legumes was less than 10% in all resource groups and seasons, an observation also noted in the eastern parts of the country for both high rainfall (Zingore *et al*., 2007) and low rainfall areas (Twomlow, 2004; Mtambanengwe & Mapfumo, 2005).

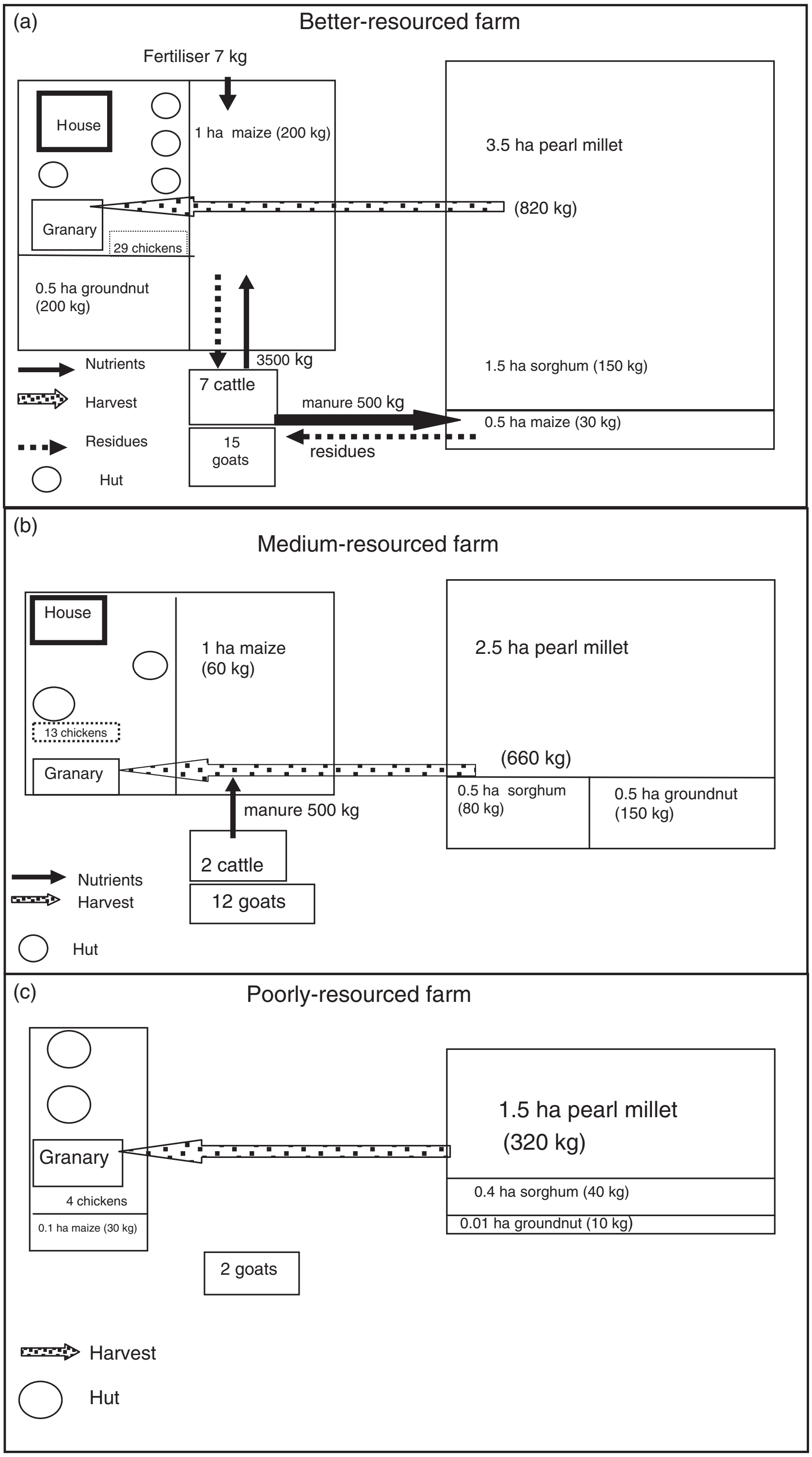

Figure 4 Resource flow maps of (a) better resourced, (b) medium resourced and (c) poorly resourced farmer classes found in Mkhubazi, Tsholotsho, Zimbabwe. The maps represent average values, and crop production levels are based on average rainfall season (590 mm).

Seasonal crop production

Cereal production. All farmers grew crops with the objective of meeting household subsistence needs until the next harvest, consistent with the findings of Ahmed *et al*. (1997). Surplus yield from the previous harvest was only sold when farmers were convinced of good yield prospects in the new season. Farmers grew more cereals than legumes across the three seasons. It was difficult to quantify grain productivity in terms of kg/ha because farmers did not plant their fields

Table 3 Average cereal production per household wealth class across three seasons (2002–2005), Mkhubazi, Tsholotsho, Zimbabwe

	Farmer wealth class		
Crop/season	Better resourced (n = 7)	Medium resourced (n = 6)	Poorly resourced (n = 7)
Millet (kg per farm)			
2002/2003	502	432	107
2003/2004	1167	1062	574
2004/2005	800	490	278
Sorghum (kg per farm)			
2002/2003	67	33	51
2003/2004	193	111	160
2004/2005	207	83	87
Maize (kg per farm)			
2002/2003	58	0	6
2003/2004	393	143	93
2004/2005	99	40	0
Total cereal production (kg per farm)			
2002/2003	466	388	164
2003/2004	1753	1316	604
2004/2005	1106	613	365
P-values for total cereal production			
Class	< 0.001		
Season	< 0.001		
SED for total cereal production			
Class	196		
Season	119		

Table 4 Cereal requirements, production and deficits/surpluses observed across three seasons (2002–2005) at Mkhubazi, Tsholotsho, Zimbabwe

Class	Season	Grain required (kg)	Grain produced (kg)	Deficit/ surplus (kg)
Better resourced	2002/2003	1354	543	−811
	2003/2004	1354	1753	399
	2004/2005	1354	1106	−248
Medium resourced	2002/2003	960	465	−495
	2003/2004	960	1316	356
	2004/2005	960	613	−347
Poorly resourced	2002/2003	789	164	−625
	2003/2004	789	604	−185
	2004/2005	789	365	−424

Grain requirement figures were calculated using actual monthly grain consumption values provided by the farmers. Yields were also based on values given by the individual farmers.

in regular patterns, and harvested in a piecemeal fashion to meet household requirements. This was particularly the case for maize which was frequently harvested green. Production per household was easier to compute as farmers used 50 and 90 kg bags to measure the shelled produce. However, where appropriate estimates of average yields per ha are given in the text. The largest cereal producers in each season were the better resourced farmers. Table 3 shows cereal production per farm per season and total cereal production by the three farmer classes across the three seasons.

Cereal yields were largely determined by the rainfall received each season (Figure 3 and Table 3). The lowest yields were harvested in 2002/2003, the driest year of the observation period, and all households in all resource classes had a grain deficit (shortage) with cereal yields ranging from as little as 0 kg/ha for maize and sorghum to as high as 300 kg/ha for pearl millet. The better resourced farmers were able to use reserves from their granaries, whereas the medium and poorly resourced farms required relief assistance. Table 4 shows cereal requirements per class, total production and the deficits or surpluses incurred each season.

In 2003/2004, the wettest season of the observation period, the better resourced group had an average surplus of cereal grain of about 400 kg, after meeting their seasonal food requirements. The medium resourced farms also met their grain needs and had a surplus close to 360 kg. The poorly resourced farms harvested the least grain in 2003/2004, and they had a 200-kg deficit despite the good rainfall. At the end of the 2004/2005 season, all farmer groups had a grain deficit of typically 250 kg for the better resourced households, 350 kg for medium resourced and at least 400 kg for the poorly resourced class.

The main cereal grown by Mkhubazi farmers during the three seasons was pearl millet constituting about 80% of all cereal production, with yields ranging between 150 and 500 kg/ha followed by sorghum (0–350 kg/ha) and maize (0–300 kg/ha) (Table 3). This is in contrast with high rainfall regions of Zimbabwe where maize is the major cereal (Zingore *et al*., 2007). All farmers cultivated sorghum but it constituted only about 10–20% of the total harvest. Maize was mainly planted by the better resourced farmers, but their yields were low except in the 2003/2004 when the total maize harvest was about 400 kg per farm. The medium resourced and poorly resourced farms only harvested more than 50 kg of maize in the wet 2003/2004 season. The maize was predominantly planted in home fields and the crop received almost all of the fertility inputs applied to croplands, including fertilizer. The low maize yields were probably due to the poor quality of the manure applied. Most of the maize is normally eaten as green mealies, which probably partly explains the low maize grain yields observed. Discussions with farmers revealed that millet is grown as a food security crop. Due to the crop's drought resistance, farmers believe that they are assured of a harvest even during dry seasons as confirmed in Table 3. Yet, all available nutrient resources are applied to the maize crop.

Legume production. Legumes were grown on less than 10% of the total cropped area in almost all farms and their yields were in contrast to those of cereals (Table 5). Groundnut was the major legume produced, mainly by the better resourced farms, which harvested more than 100 kg in all three seasons, but never achieved equivalent yield levels of more 0.5 t/ha. This was more than double the yield of the medium resource farmers who, on average, planted a similar area (0.5 ha) each season but grew their groundnuts in the main field rather than in the home field (Figure 4a,b).

It is generally thought that cowpea is the most planted legume in smallholder farms (Madamba *et al*., 2001); this study found the opposite. Cowpea was the least planted and most farms recorded zero grain yields from the little that was grown. The leaves of the cowpea are picked throughout the vegetative period and eaten as a relish, providing a dietary supplement during the growing season. Bambara groundnut yields were the highest (about 150 kg) during the wetter season in 2003/2004 in the medium resourced and better resourced farms. The poor yields in the dry seasons were probably a result of moisture limitation. Poorly resourced farmers harvested no Bambara groundnut at all, despite the crop being a traditional legume considered to be highly resistant to drought. We tried to find the reasons for such limited legume cultivation and productivity by interviewing individual farmers about legume problems during the last season (2004/2005) (Figure 5).

Lack of quality seed was cited as one of the major reasons for not growing legumes or not planting larger areas of legumes (85% of respondents) in Mkhubazi. This is consistent with conclusions of previous studies, which suggested lack of seed as one of the major problems faced by smallholder farmers in Zimbabwe and throughout much of southern Africa (Shumba, 1983; Hilderbrand, 1996; Twomlow, 2004). Legumes such as Bambara groundnut and groundnut are large seeded and therefore need high seeding rates. Combined with the high cost of legume seed, this might be the real barrier to farmers planting larger areas with legumes, especially in the absence of good market linkages to sell surplus.

Those farmers who had planted small areas of legumes reported major problems with rodents during the 2004/2005 season, especially in cowpea. However, it appeared that the rodent problem was a rare outbreak. Other pests such as leaf eaters and cutworms were a minor problem. Aphids and drought problems were reported by less than 20% of the farmers. None of the farmers mentioned poor soil fertility as a problem in legume production. One would expect P to be a major limiting factor, but the farmers seemed to be in agreement with the findings by Ncube *et al*. (2007) who also could not cite P as a limiting factor in soils in the same area. This is in contrast with the findings by Waddington & Karigwindi (2001) and Mupangwa & Tagwira (2005), who reported poor soil fertility as a major reason for poor groundnut production in smallholder farms in eastern Zimbabwe.

Table 5 Average legume production per household wealth class across three seasons (2002–2005), Mkhubazi, Tsholotsho, Zimbabwe

	Farmer wealth class		
Crop/season	Better resourced (n = 7)	Medium resourced (n = 6)	Poorly resourced (n = 7)
Groundnut (kg per farm)			
2002/2003	148	37	24
2003/2004	362	40	0
2004/2005	280	42	12
Cowpea (kg per farm)			
2002/2003	2	1	5
2003/2004	54	13	5
2004/2005	21	2	3
Bambara (kg per farm)			
2002/2003	10	14	0
2003/2004	149	133	0
2004/2005	79	91	14
Total legume production (kg per farm)			
2002/2003	137	44	29
2003/2004	484	186	4
2004/2005	380	134	29
P-values for total legume production			
Class	0.002		
Season	ns		
SED for total legume production			
Class	103		
Season	129		

ns, not significant.

Soil fertility management strategies and nutrient balances

Soil fertility management strategies followed by the Mkhubazi farmers confirmed the soil fertility management crisis reported by Mapfumo & Giller (2001). Inorganic fertilizer

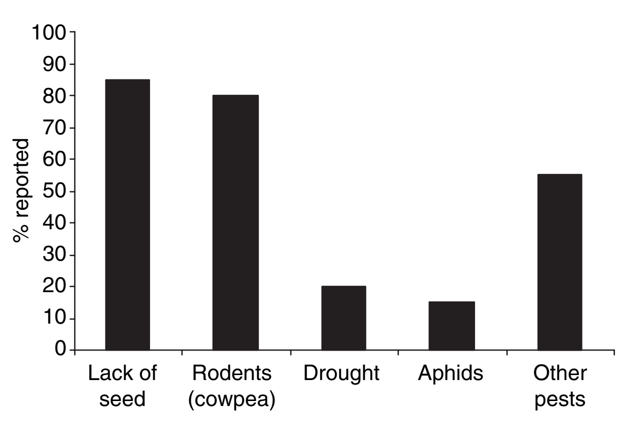

Figure 5 Reasons given by farmers for limited production of grain legumes in Mkhubazi, Tsholotsho, Zimbabwe (n = 20).

use was negligible within the farming system. Only two farmers in the better resourced and medium class categories used basal fertilizer once (compound D) during the three seasons, at less than 50 kg/ha. Three better resourced farmers applied ammonium nitrate as top dressing in the wetter 2003/2004 season (average 7 kg/ha). These results indicate a decline in fertilizer use compared with the previous decade (Ahmed *et al.*, 1997). Farmers did not buy fertilizer because it was not locally available, and when available it could only be bought in 50-kg bags, which were considered too expensive. All farmers in the three classes applied household ash to the home fields, although the amounts were difficult to quantify.

Manure was the major organic source of nutrients used by the better resourced and medium resourced farms (Figure 6a). The manure was applied at average amounts of 5000 kg/year per farm (better resourced farms, equivalent to less than 3 t/ha/year), 1000 kg/year per farm (medium resourced farms, equivalent to less than 1 t ha/year) and negligible amounts in the poorly resourced farms. Farmers applied manure on any field that had shown signs of poor fertility such as the yellowing of leaves in the previous season's cereal crops. There was no deliberate effort to improve soil fertility of the whole field. This is in contrast with farmers in high rainfall areas who applied large amounts of manure to fields that were closer to the homesteads (Zingore *et al.*, 2007). In Mkhubazi, maize was always planted in fields that had received manure that season, although two farmers in the better resourced class also applied manure to sorghum. Millet never received manure directly, but the crop was planted after maize in the main fields, and may therefore benefit from some residual effects. Manure was never used on legumes. Farmers in the poorly resourced class used virtually no manure, although one poorly resourced farmer reported that she collected cow dung from around the dip tank one season to use in her fields. Chicken manure was used in the small vegetable gardens of some farmers, but due to water shortage in the dry season little was grown in the gardens.

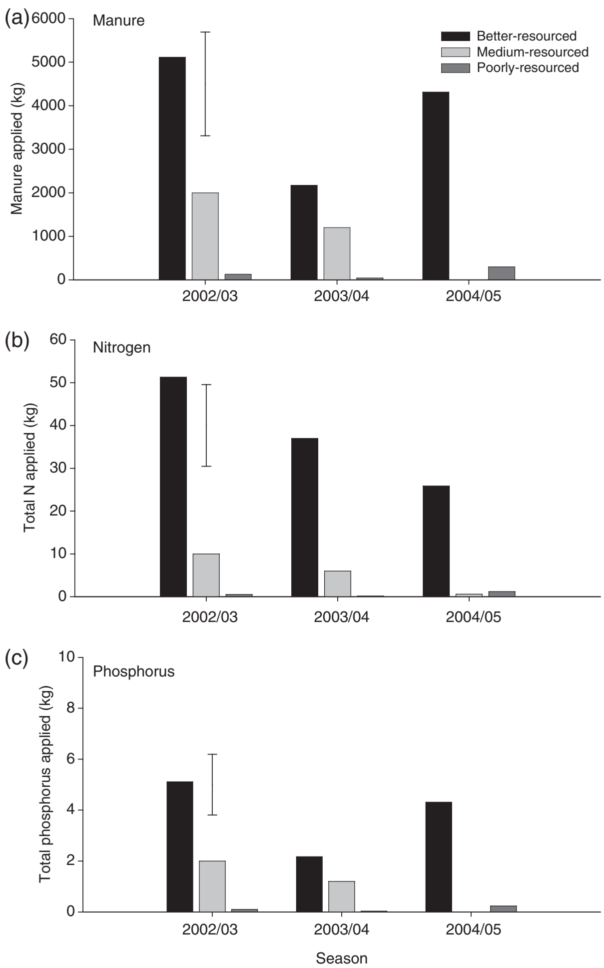

Figure 6 Manure (a), total N (b) and total P (c) applied by the different farmer resource classes across the seasons, Mkhubazi, Tsholotsho. Calculations of N and P content were based on the manure analysis results reported by Ncube *et al.* (2007). The error bars represent standard errors of differences between farmer classes.

The amount of manure applied varied widely from year to year (Figure 6a). The main reason for the small manure use in 2003/2004 was insufficient production during the drier 2002/2003 season. In very dry seasons, the supply of manure is restricted because farmers graze animals in the forest, for up to 3 months, before the start of the rainy season.

Crop residues were primarily grazed *in situ* by livestock from the whole village; hence, there is a net export of both the grain and stover from all fields. However, better resourced and medium resourced farms did carry a proportion (about 50%) of the maize residues to the homestead for dry season feeding of livestock when kraaled at night. Calculations of the total N and P applied per season using N and P content values measured by Ncube *et al.* (2007) showed that the better resourced farms were applying up to a maximum of 50 kg N per farm per season (Figure 6b), mainly from manure. The medium resourced and poorly resourced classes, however, applied less than 10 kg of N. As the P source was also manure, the seasonal variations were similar to that of manure availability (Figure 6c); the amounts of P applied were always less than 10 kg per farm. Total N applied decreased across the seasons. The large amount of N used in the 2003/2004 season was due to more N fertilizer purchased for top-dressing during the wetter rainy season.

The partial N balance of the resource groups showed that the medium resourced and poorly resourced farms were mining the soil every season (Table 6). In 2002/2003, the better resourced class had a large positive N balance due to the large amounts of manure applied, whereas the medium resourced and poorly resourced groups had slightly negative N balances. The more favourable N balances in 2002/2003 were due to reduced uptake by crops as almost all farmer groups harvested low crop yields. However, in a wetter

Table 6 Partial N balance across three cropping seasons (2002–2005) at Mkhubazi, Tsholotsho, Zimbabwe, for three classes: better, medium and poorly resourced households

	Wealth class		
Season	Better resourced (n = 7)	Medium resourced (n = 6)	Poorly resourced (n = 7)
2002/2003			
N applied (kg)	51	10	1
N removed (kg)	16	16	5
Partial balance (kg)	25	−4	−6
2003/2004			
N applied (kg)	37	6	0
N removed (kg)	59	44	24
Partial balance (kg)	−25	−38	−23
2004/2005			
N applied (kg)	26	1	1
N removed (kg)	37	21	12
Partial balance (kg)	−11	−20	−11

The partial balance calculations are based on nutrients supplied by manure and fertilizer, nutrients contained in grains removed and the values are calculated per average farm in each wealth class. The figures do not include contributions from soil mineralization and atmospheric deposition.

season (2003/2004) all the farmer classes had strongly negative N balances due to greater production and subsequent removal. In 2004/2005 the medium resourced class had the worst N balance indicating that the rates of manure applied by the group was not enough to replenish soil N that season.

Conclusions

This study has shown that that all farmers irrespective of their wealth status share a common goal in farming – household food security. The main driver of the Tsholotsho farming system is rainfall, although soil fertility is also a key issue as it determines the efficiency with which the available water is used for crop production. Small grains (particularly pearl millet) were the main cereals grown for consumption and for long-term food security, but when farmers had nutrient resources (manure or fertilizers) available they were invariably targeted on maize. This confirms the common preference of farmers in the semi-arid regions of southern Africa for maize due to the ease of processing, the lack of bird attack and consumer preference despite the better production of millet and sorghum under dry conditions (Mapfumo & Giller, 2001). Legumes were grown on very small areas within the system with lack of good quality seed being the major constraint.

Soil fertility is poor in most Tsholotsho fields. The main practice to replenish soil fertility was manure application, but at rates far below those recommended or required to ensure good crop yields. The amount of manure available varied greatly between years due to changes in the grazing system in times of drought. Poorly resourced farmers had no means of managing soil fertility as they owned no livestock and they had no money to purchase inorganic fertilizer. Overall, there was inadequate nutrient replacement in all farms, resulting in large negative N and P balances.

Coping strategies of households in Tsholotsho include money remittances from relatives outside the country or directly earning food from the so-called 'food for work' schemes, and on food handouts during drought years, a situation not dissimilar to much of the drier areas of sub-Saharan Africa (Ryan & Spencer, 2001). Further research to test potential strategies for developing sustainable production systems within the context of the extended livelihoods of the rural households (Giller *et al*., 2006) are urgently required to address the problems of food security in the semi-arid parts of the country and the region. This could include, for example, developing seed systems that could ensure the availability of cheap good quality legume seed.

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