Zentrum für Entwicklungsforschung

Improving the water productivity of integrated crop-livestock systems in the semi-arid tropics of Zimbabwe: an ex-ante analysis using simulation modeling

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ABSTRACT

The semi-arid tropics of Zimbabwe are characterized by low economic activity, high incidence of land degradation and a high concentration of the rural poor. Water scarcity is also a principle constraint, and available water is used ineffectively as evidenced by low crop and livestock water productivity. Low crop productivity is partly attributed to inherent low soil fertility, and this is further exacerbated by continuous cropping without addition of adequate organic and inorganic fertilizers due to unavailability and high costs. Feed shortages, especially during the dry season, high incidence of diseases and high mortality rates cause low livestock productivity. In this study, soil fertility and feed issues are addressed as they are perceived as constraints where solutions are within the farmers' capabilities. On-farm surveys and field experiments were done in Nkayi district in northwest Zimbabwe to assess the current situation in the crop-livestock systems. A simulation modeling approach was used to evaluate potential interventions that can be used as entry points to improve crop and livestock water productivity. Differences in access to key resources such as labor, land, farm implements and traction power affect overall crop and livestock productivity, hence three farmer wealth categories were considered, namely poor, average and better-off.

Crop and livestock production are the main livelihood activities in all three wealth categories. Average cultivated land was 3 ha and fallow land was 1 ha per household. Livestock holdings, which include cattle, donkeys and goats, were 2.8, 6.8 and19.6 tropical livestock unit (TLU) in the poor, average and better-off wealth categories, respectively. Soil fertility in terms of nitrogen, phosphorus and organic carbon is very low with average values of 0.04, 0.01 and 0.37%, respectively. Crop and livestock water productivity is also very low with average values of 0.04 kg m^{-3} and US$ 0.02 m^{-3}, respectively.

Low-cost interventions that use locally available organic inputs are evaluated using the Agriculture Production Systems Simulator (APSIM) and feed deficits using the MLA Meat and Livestock Australia (MLA) feed demand calculator. Interventions are farmer practice (FP), manure (MN) and maize-mucuna rotation (MMR). Their potential effects on crop water productivity, soil fertility and contribution to dry-season feed are assessed. Average maize grain water productivity is 0.34 0.42 and 0.76 kg m^{-3} under the FP, MN and MMR treatments, respectively, while that of mucuna (*Mucuna pruriens*) is 1.34 kg m^{-3}. Cropping under the FP and MN treatments shows negative trends in SOC and TN over 30 years across all wealth categories, with losses ranging from 17 to 74 kg ha^{-1} yr^{-1} and 6 to 16 kg ha^{-1} yr^{-1}, respectively. In contrast, the MMR treatment shows positive trends in both soil organic carbon (SOC) and total nitrogen (TN) in the poor and average wealth categories, while in the better-off these values did not change. SOC and TN increase by 2.6 to 194 kg ha^{-1} yr^{-1} and 6 to 14 kg ha^{-1} yr^{-1}, respectively.

Crude protein (CP) content in maize stover is 29, 32 and 82 g kg^{-1} in the FP, MN and MMR treatments, respectively. The potential contribution to daily feed requirements during the dry season in terms of dry matter (DM), CP and metabolizable energy (ME) of stover and mucuna biomass is also evaluated. Maize stover obtained in the FP and MN treatments cannot supply 100% of the daily required DM, CP and ME. Stover and mucuna biomass in the MMR treatment can supply 100% of daily required DM, CP and ME in the poor and average wealth categories and 50% DM and 100% CP and ME in the better-off category. The results of the study show that the maize-mucuna treatment has the potential to improve soil fertility and crop and livestock water productivity in the semi-arid smallholder farming systems of Zimbabwe.

KURZFASSUNG

Die semiariden Tropen Zimbabwes sind durch eine geringe Wirtschaftskraft, arme Landbevölkerung und fortgeschrittene Landdegradation gekennzeichnet. Wasserknappheit ist ein limitierender Faktor und gleichzeitig wird das vorhandene Wasser ineffizient genutzt. Dies führt zu einer niedrigen Produktivität sowohl im Pflanzenbau als auch in der Viehhaltung. Neben dem Wassermangel wird die niedrige Produktivität auch auf eine niedrige Bodenfruchtbarkeit zurückgeführt. Diese wird noch durch permanente Landnutzung (ohne oder mit verkürzten Brachephasen) mit mangelhafter Düngung, bedingt durch Düngermangel und hohe Beschaffungskosten verstärkt. Die niedrige Produktivität in der Viehhaltung ist eine Folge von Futterknappheit während der Trockenzeit sowie häufig auftretender Seuchen und hoher Mortalitätsraten. Die vorliegende Studie beschäftigt sich mit Fragen der Bodenfruchtbarkeit und der Viehfutterbereitstellung, da angenommen wird, dass dies Probleme sind, die durch die betroffenen Bauern selbst gelöst werden können.

Im Nkayi-Distrikt im Nordwesten Zimbabwes wurden Untersuchungen auf ausgewählten Farmen sowie Feldversuche durchgeführt, um die aktuelle Situation der Anbau- und Viehhaltungssysteme zu erfassen. Potentielle Maßnahmen zur Steigerung der Produktivität durch verbesserte Wassernutzung im Anbau und in der Viehhaltung werden durch Modellsimulation (Agriculture Production Systems Simulator; APSIM) ermittelt. Unterschiede im Zugang zu wichtigen Ressourcen wie Arbeitskräfte, Land, landwirtschaftliche Geräte und Zugtiere bzw. -maschinen beeinflussen den Ertrag der Pflanzen- und Tierproduktion. Daher werden drei Wohlstandskategorien betrachtet: arme, durchschnittlich wohlhabende Farmer und wohlhabende Farmer.

Ackerbau und Viehhaltung sind die wichtigsten Aktivitäten in allen drei Kategorien. Die durchschnittliche Größe einer Farm beträgt 4 ha, davon werden 3 ha für den Pflanzenbau genutzt und 1 ha als Brache. Der durchschnittliche Viehbestand (Rinder, Esel, Ziegen) beträgt 9.5 tropische Großvieheinheiten (TLU). Die Bodenqualität ist gekennzeichnet durch niedrige Stickstoff-, Phosphor- und organische Kohlenstoffwerte in Höhe von 0.04, 0.01 bzw. 0.37%. Die Wasserproduktivität im Pflanzenbau und in der Viehhaltung ist ebenfalls sehr niedrig mit durchschnittlichen Werten von 0.04 kg m^{-3} bzw. 0.02 US$ m^{-3}.

Maßnahmen mit geringen Kosten, die auch lokal verfügbare organische Dünger nutzen, werden mit APSIM modelliert. Zur Ermittlung des Futterbedarfs des Viehs wird der Meat and Livestock Australia (MLA)-Rechner eingesetzt. Die gewählten Maßnahmen sind: von den Farmern üblicherweise eingesetzte Maßnahmen (FP), organische Düngung (MN) und ein Fruchtwechsel von Mais und Mucuna (*Mucuna* pruriens) (MMR). Die potentiellen Auswirkungen dieser Maßnahmen auf die Wasserproduktivität im Pflanzenbau, auf die Bodenfruchtbarkeit und die Futterproduktion in der Trockenzeit werden geschätzt. Die durchschnittliche Wasserproduktivität bei Maiskörnerertrag beträgt 0.34, 0.42 bzw. 0.76 kg m-3 bei FP, MN bzw. MMR und bei Mucuna 1.34 kg m-3. FP bzw. MN zeigt einen negativen Trend hinsichtlich des organischen Kohlenstoffs im Boden (SOC) und des Gesamtstickstoffgehalts (TN) simuliert über 30 Jahre mit einer Abnahme von 17 bis 74 kg ha-1 Jahr-1 bzw. 6 bis 16 kg ha-1 Jahr-1. Im Gegensatz hierzu zeigt MMR einen positiven Trend sowohl bei SOC und TN in den Wohlstandskategorien arm und durchschnittlich, während in der Kategorie wohlhabende Farmer sich die Werte nicht verändern. SOC und TN nehmen 2.6 bis 194 kg ha-1 Jahr-1 und 6 bis 14 kg ha-1 Jahr-1 zu.

Der Roheiweiß-(CP)-Gehalt der Maisernterreste beträgt 29, 32 bzw. 82 g kg^{-1} bei FP, MN bzw. MMR. Der potentielle Beitrag zum täglichen Futterbedarf hinsichtlich Trockenmasse (DM), CP und metabolisierbare Energie (ME) der Biomasse der Maisernterreste und von Mucuna wird ebenfalls geschätzt. Die Maisernterreste können bei FP und MN nicht 100% des täglich benötigten DM, CP und ME liefern. Jedoch können Maisernterreste und Mucunabiomasse bei MMR diese Menge bei den Kategorien arme bzw. durchschnittlich

wohlhabende Farmer liefern und ca. 50% DM und 100% CP und ME bei den wohlhabenden Farmern. Die Ergebnisse der Studie zeigen, dass der Mais-Mucuna-Fruchtwechsel das Potential hat, die Bodenfruchtbarkeit und die Wasserproduktivität sowohl im Pflanzenbau als auch in der Viehhaltung kleinbäuerlicher Systeme in den semiariden Regionen Zimbabwes zu verbessern.

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1 GENERAL INTRODUCTION

1.1 Background

Agricultural production systems as currently practiced by farmers in the semi-arid tropics of sub-Saharan Africa (SATSSA) are different from those used in the past, and in this process of transition the agricultural systems are showing disequilibrium dynamics particularly of nutrient outflows, which exceed inflows (Abegaz 2005). The climatic and socioeconomic changes occurring in many parts of the region are rapidly transforming traditional, extensive crop and livestock management practices, based on shifting cultivation and transhumance, to more sedentary forms of production (Powell et al. 2004). On the other hand, the SATSSA is experiencing vast increases in human population pressure. To meet the demands of the growing population, farmers are forced to extend cropping activities to marginal lands, rangelands and forest areas resulting in livestock marginalization, reduced fallow periods and ecological degradation (Muhr 1998; Powell et al. 2004; Abegaz 2005). High incidence of land degradation has caused crop production to stagnate over the past decades, with yields of major cereal crops (maize, sorghum, millet) being in the range of 0.5 to 1 t ha^{-1} (Mellor et al. 1984; Powell et al. 2004; O'Gorman 2006). There is also ample evidence that crop water productivity is low, as transpiration is generally reported to account for merely 15-30% of rainfall while 70-85% of rainfall is considered 'lost' to the cropping system as non-productive green-water flow (as soil evaporation) and blue-water flow (deep percolation and surface runoff) (Rockström et al. 2003).

1.2 Water productivity

Water productivity is generally defined as crop production per cubic meter of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from systems) for irrigated areas (Cai and Rosegrant 2003). It can be improved by producing the same output with less water or by increasing output for the same amount of water (Mustafa et al. 2008). Recently, it has been recognized that livestock feed production depletes large amounts of global fresh water, and consequently, the concept of increasing livestock water productivity (LWP) is emerging (Peden et al. 2007). LWP is a new concept that is theoretically defined as the ratio of livestock products and services to the amount of water used in producing these products and services (Peden et al. 2007). In order for livestock feed needs to be met in the SATSSA, water management is essential in existing farming systems, as livestock consume up to 100 times more water (in feed) than they drink, thus there is a need to concentrate on feed production systems with higher water productivity (Peden et al. 2007).

The major components that directly affect LWP have been identified as type, quality and amount of forage/feed crops produced, amount of water used to grow these feeds, productivity level of the animal using these feeds, which could be affected by breed, animal health and management conditions, quality of veterinary services and other socio-economic incentives (Peden et al. 2007). One key strategy for increasing LWP lies in selecting feed sources that use relatively little water or that use water that has little value for other human needs or for the support of ecosystem services (Peden et al. 2009). It has been argued that crop residues are already the single most important feed resource in many livestock production systems in developing countries, and that increasing their contribution to livestock feeding needs to be linked to improving their fodder quality (Blümmel et al. 2009).

Water productivity of cereal grain in sub-Saharan Africa currently ranges from 0.04 to 0.1 kg m^{-3} while the potential is more than 1.0 kg m^{-3} (Rockström et al. 2003). The low productivity is partly attributed to inherent low soil fertility and impoverishment is further exacerbated by continuous cropping without addition of adequate organic and inorganic fertilizers due to unavailability and high costs (Nzuma et al.1998; Mugwe et al.2004). On the other hand, livestock production is also low as evidenced by the milk production, which averages below 500 kg per lactation with off take rates ranging from 1.5 to 3% per annum (Barret 1991; Ngongoni et al. 2006; Mapiye et al. 2009). To improve production, a combination of soil fertility, water management, feeding and animal productivity enhancement strategies need to be employed.

Soil fertility and livestock production have been successfully improved through inclusion of forages in cropping systems or growing of forage crops to rehabilitate degraded rangelands in countries like Nicaragua (Jaragua grass, *Hyparrhenia rufa*), Kenya (Napier grass, *Pennisetum pupureum*), Egypt (Berseem, *Trifolium alexandrinum*) and in Indonesia (*Leucaena leucocephala*) (Bayer and Waters-Bayer 1998). Cultivated forage crops can be used to complement natural pasture feed, improve soil quality, reduce soil erosion, be used for firewood, as live fences, thatching etc. In Zimbabwe, different types of forages (*Lablab purpureus, Mucuna pruriens, Medicago sativa*, *Cajanus cajan, Chloris gayan, Pennisetum purpureum*) have been introduced to commercial and communal farmers in subhumid areas, where productivity was improved through provision of high quality feed and alternative low-cost fertilizers for crop production (Maasdorp and Titterton 1997; Ngongoni et al. 2007).

Integration of livestock feed needs in existing farming systems could enable smallholder farmers to get more from their animals while using the same amount of water. Increasing the water productivity in agriculture will play a vital role in easing competition for scarce water resources, preventing environmental degradation and providing food security. Forage legumes have the potential to improve both crop and livestock productivity in smallholder farming systems, but their benefits have not yet been fully explored especially in the semi-arid tropics of Zimbabwe. To understand the extent of the beneficial effects of forage legumes in mixed crop-livestock systems a significant amount of resources is required such as time and money, which makes the option of field experimentation not viable. Well proven crop models can be useful evaluation tools instead of lengthy and expensive field experiments (Steduto et al. 2009).

1.3 Modeling approach

Crop-livestock water productivity involves many intrinsically related factors such as land management, and bio-physical and socio-economic. Consequently, for research and development to have an impact on crop-livestock production these factors need an integrated approach spatially and temporally. Simulation modeling provides a valuable framework for systems analysis of farming systems. By capturing the current scientific understanding of biophysical determinants of crop growth and livestock productivity, mechanistic models offer a great potential for system analysis of integrated crop-livestock farming systems.

There are many models that have been developed to simulate crop and livestock growth processes such CERES-MAIZE, APSIM, DSSAT and GRAZE; each has its capabilities and limitations (Loewer 1998; Matthews 2002). The Agriculture Production Systems Simulator (APSIM) has been developed to simulate biophysical processes in farming systems in relation to the economic and ecological outcomes of management practices in the face of climate risk (McCown et al. 1996; Keating et al. 2002). The APSIM model has been tested in Africa to evaluate crop production under a wide range of management systems and conditions and it became an accessible tool for developing intervention strategies targeted at smallholder farmers (Whitbread et al. 2010).

1.4 Rationale

Inclusion of forage legumes and use of locally available organic resources such as manure and crop residues offer the most realistic opportunities for smallholder farmers in mixed crop-livestock systems to improve soil fertility, crop production and feed quality and quantity especially during the dry season. Many studies that focused on crop and livestock production are based on a single crop and often a single resource while, in reality agricultural production suffers from multiple constraints, so interactions between resources are often critical in determining overall productivity (Giller et al. 2005). Crop and livestock in mixed farming systems complement each other and at the same time compete with each other for resources such as crop residues. The challenge is how to determine the potential productivity of these systems and to what extent they can satisfy both crop (soil improvement) and livestock (feed needs).

1.5 Objectives

The general objective was to quantify crop-livestock water productivity in current farming systems and evaluate management interventions that can improve crop-livestock water productivity under rain-fed farming systems. The specific objectives were as follows:

1. To understand the determinants of wealth as described by farmers and to assess the importance of different livelihood activities, and also to define the constraints and opportunities in mixed crop-livestock production systems.
2. To explore the magnitude of physical crop and financial livestock water productivity in current farming systems as affected by household resources ownership.

3. To assess potential biomass production of cultivated forages under smallholder farming systems, and to evaluate the predictive performance and robustness of APSIM by comparing the simulated maize grain and stover and mucuna biomass yield and the nitrogen content in stover and mucuna biomass against field and laboratory measurements.
4. To evaluate long-term effects of different treatments on maize and mucuna water productivity, dynamics of soil organic carbon and total nitrogen, and to investigate the degree of water and nitrogen stress under different fertility treatments, across seasons.
5. To evaluate potential feed demand and supply of natural pastures and potential feed deficits over one year for livestock under three farmer wealth categories and to assess the potential contribution of maize stover and mucuna biomass to livestock feed requirements during the dry season and the implications for livestock water productivity.

1.6 Outline of thesis

Following the general introduction, Chapter 2 details the determinants of wealth as described by farmers and the different livelihood activities of the farmers. The importance of crop and livestock production and constraints and mitigation strategies employed by the farmers are also described.

Chapter 3 describes the farmers' reasons for keeping livestock and the beneficial products and services obtained from livestock. Heterogeneity in key resources (land and livestock holdings) is also explored. Using the livestock and land holding data, crop and livestock water productivity was quantified.

One of the potential entry points to improve crop-livestock production is including forage legumes in current systems, hence potential production of such cropping systems using field experiments and a crop model was tested in Chapter 4. The predictive performance and robustness of the APSIM model against measured maize and mucuna yield data was also assessed.

In Chapter 5 crop production scenarios were formulated and tested using the APSIM model. The effects of the different treatments on crop water productivity and soil fertility were evaluated.

Chapter 6 details the seasonal changes in livestock weight and milk production and periods of feed shortages as described by farmers. Potential feed shortages from natural pasture and the potential of crop residues obtained under different crop production systems (Chapter 5) in filling feed gaps especially during the dry season are explored.

2 ASSESSMENT OF CROP-LIVESTOCK SYSTEMS IN SMALLHOLDER FARMING SYSTEMS OF ZIMBABWE: A CASE STUDY OF NKAYI DISTRICT

2.1 Introduction

Integrated crop-livestock farming is the predominant system of production and subsistence in communal farming systems of Zimbabwe. This farming system is mainly based on maize, sorghum, groundnuts and cowpeas as staple crops, combined with the use of communal rangelands and fallow land for livestock production. The principal cereal crops are maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench) and pearl millet (*Pennisetum glaucum* L.*)*, and household livestock holdings vary from a few to a hundred heads per household with varying ratios of cattle (*Bos taurus*), donkeys (*Equus asinus*), and goats (*Capra hircus*) (ICRISAT survey 2008). Livestock play an important role in these farming systems, as they offer opportunities for risk coping, farm diversification and intensification, and provide significant livelihood benefits (Williams et al. 2002; Bossio 2009). Animals are kept to compliment cropping activities through the provision of manure for soil fertility maintenance, draft power for cultivation, transport, cash and food (Williams et al. 2002; Powell et al. 2004; Peden et al. 2009).

Agriculture is the mainstay of the national economy accounting for about 15 to 20 percent of the GDP. It provides income and employment for a substantial percentage of the population (FAO 2001). The sector also generates a large proportion of foreign exchange earnings, although the share of agricultural exports in the country's total exports has declined from 39% in 2001 to 14% in 2006 with some relative improvements in 2008 and 2009 (FAO/FWP 2009). The population in Zimbabwe is estimated to increase from the current 12 million to about 16 million in 2030. From 1965 to 1996, average daily per capita energy requirement increased from 2109 to 2159 kcal, and it is expected to reach 2261 kcal by 2030 (FAO 2006). The increasing trends in energy requirements in Zimbabwe reflect the changes in population structure, age, sex and in particular urban-rural distribution (FAO 2006). The urbanization rate has more than doubled from 14.4% to 32.5% between 1965 and 1996 and is projected to increase again to 52.2% by 2030 (FAO 2006). With continuing urbanization, food habits change toward more nutritious and more varied diets, i.e. there is an increasing consumption of staple cereals but also a shift in consumption patterns among cereal crops and away toward livestock and fish products and high-value crops (Comprehensive Assessment of Water Management in Agriculture 2007).

It is projected that consumption of livestock products will double in most developing countries in the near future, Zimbabwe included. The rapidly increasing demand for meat and dairy products in these areas can improve the economic activities and benefit the rural poor or it can drive them deeper into poverty (Peden et al. 2007). The former outcome can only be achieved if the capacity and limitations of the natural environment and farmers' socio-economic conditions in the current production systems are considered. It is important to note that currently most crop-livestock production relies directly on rainfall, and adverse changes in quantity and temporal pattern of rainfall are a major risk to production. In addition, declining soil fertility and high prevalence of pests and diseases coupled with limited resources is severely limiting crop production in most smallholder farming systems. In order to ensure meaningful research interventions, it is therefore important to undertake an appropriate assessment of the current crop-livestock farming systems. Consequently, the objectives of this study were to (i) understand the determinants of wealth and different livelihood strategies as described by farmers, (ii) assess the importance of different farmer livelihood activities, and (iii) elucidate on constraints and opportunities in crop-livestock production systems.

2.2 Material and methods

2.2.1 Study site

The study was conducted in Nkayi district located in Matebeland North Province which lies in the northwestern part of Zimbabwe. Zimbabwe is divided into five agro-ecological regions, known as natural regions, on the basis of rainfall regime, soil quality, and vegetation among other factors (Vincent and Thomas 1961, also see FAO 2006 for descriptive maps). Nkayi district is located in the natural region IV, which is characterized by low annual rainfall (450-650 mm), severe dry spells during the rainy season, and frequent seasonal droughts (FAO 2006). The area is also characterized by semi-extensive mixed crop and livestock farming systems. Predominant soils in the area are Kalahari sands, which are low in N, P, and S and cation exchange capacity owing to low clay and organic matter contents (Grant 1967a; 1967b; 1970; Nyamapfene 1981 cited in FAO 2006).

The district is administered from the district administrative center and is divided into 25 wards (Figure 2.1; ICRISAT survey 2008; Mazango and Munjeri 2009). Each ward consists of five to eight villages with each village consisting of largely blood-related people headed by a traditionally elected village head (Mazango and Munjeri 2009). The district has about 150 villages and a human population density of 40 people km^{-2} (Homann et al. 2007). Crop and livestock enterprises are complementary and at the same time competitive. Livestock are a source of draft power, organic fertilizer, milk and cash income. On the other hand, crop residues are fed to livestock. Due to increasing demographic pressure and demand for food, farmers are forced to extend cropping activities to marginal lands, rangelands and forest areas resulting in livestock marginalization, reduced fallow periods and ecological degradation (Muhr 1998; Powell et al. 2004; Abegaz 2005). The district was selected on the basis that it has higher cattle numbers as compared to other districts in the same natural region (Table 2.1), and that there is good potential for livestock production (Homann et al. 2007).

Table 2.1 Livestock production systems in selected districts in agroecological zone IV, in northwestern Zimbabwe

	Binga	**Nkayi**	**Tsholotsho**
Human population density (n km^{-2})*	25	40	35
Cattle population density (n km^{-2})**	77	231	139
Goat population density (n km^{-2})**	283	65	153
% household with cattle	59	81	68
Cattle head size	6.6	6.6	4.4
(household mean std.dev)	(8.9)	(5.9)	(4.8)
Goat flock size	12.6	8.8	6.8
(household mean std.dev)	(16.7)	(9.5)	(5.7)

* Source: Central Statistics Office (2002)
** Source: Department of Veterinary Services (2005) Cited in (Homann et al. 2007)

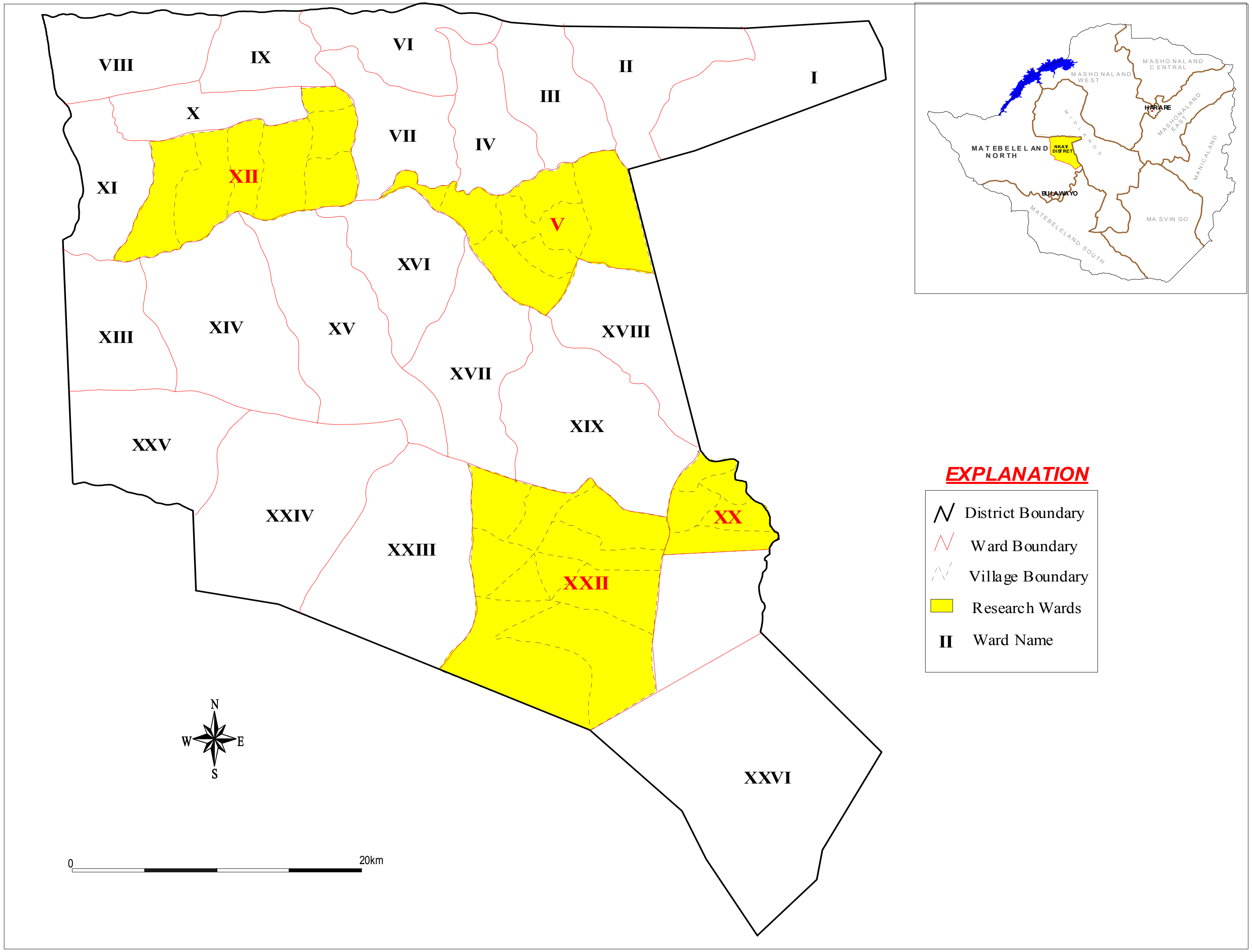

Figure 2.1 Map of the study area showing the location of the research sites

2.2.2 Community and household interviews

Participatory rural appraisals (PRA) and structured questionnaires (pre-tested) through interviews were used to collect qualitative and quantitative information on crop and livestock production in the district. The surveys and PRAs were conducted in September and October 2008. Data was collected from four wards and per each ward a village was randomly selected. About 27 farmers were interviewed per village resulting in a total number of 104 farmers who participated in the interviews. About 40 to 45 farmers from each village attended the PRA meetings. Farmers who participated in the surveys were randomly selected from the list of villagers kept by the village head. Mobilization of communities was done a week before the survey and PRA were conducted. The questionnaires were pre-tested using a few households in the study area and then adjusted before they were finally administered to farmers. Surveys were used to collect qualitative and quantitative information on livelihoods, wealth ranking, crop production, livestock ownership and dynamics, crop and livestock management technologies, constraints and opportunities. Information on livestock feeding strategies and beneficial products and services was also collected. Farmer interviews were conducted at their homesteads by trained enumerators.

For the PRA workshops, some of the attendants (key informants) were systematically selected while the rest of the farmers were randomly selected. Systematically selected farmers included traditional leaders, representatives of different organizations and farmer groups. Farmers from all age groups, wealth categories and gender were included. In order to facilitate the workshop process, the participants were split randomly into 2 groups (regardless of gender and wealth criteria), each completing different data collection exercises. A facilitator and a note taker were assigned to each group to guide the discussions and record important aspects of the group process. After completing the discussions, both groups came together and presented their findings in a plenary session. The plenary session generated broader discussions, allowed clarification of the key issues, and ensured data consistency. Notes of the plenary session were taken and used to validate and clarify the information gathered from the group discussions. In the first phase of the PRA, discussions were on livelihoods, wealth ranking, innovation actor analysis, land-use, time-line analysis, and mapping.

The second phase included issues of land-use, rangeland management, degradation and constraints in crop-livestock production.

2.3 Results

2.3.1 Wealth categories

Although smallholder farmers are generally considered poor, there are also wealth classes among them. Three categories which were put forth by the farmers were the better-off, average and poor. Although there are a number of different assets that can determine a farmer's wealth status, livestock ownership and crop production were the strongest/main determinants. Amongst livestock types, cattle were mainly considered. Households with more than 9 heads of cattle were considered to be in the better-off category (Table 2.2). Livestock ownership is accompanied by other determinants such as housing standards, farm implements, and capacity to send children to school. Crop production is substantially affected by wealth due to the availability of farming implements and accessibility to organic and inorganic soil amendments. The major crop used to determine wealth status is maize. More than 50% of the households in the villages were said to be in the poor category.

Table 2.2 Determinants of wealth categories among smallholder farmers in Nkayi district, Zimbabwe

Category determinant	**Wealth category**		
	Better-off	***Average***	***Poor***
Livestock number			
Cattle	> 9	3-8	0-2
Goats	> 12	5-11	0-4
Donkeys	> 7	4-6	0-3
Sheep	> 8	3-6	0
Maize grain yield			
Kg ha^{-1}	>1700	600-1200	0-500

Tabele 2.2 continued

Category determinant	**Wealth category**		
	Better-off	***Average***	***Poor***
Education	All children up to secondary level	2-3 children up to secondary level with selectivity	Primary level or not at all because farmers cannot afford school fees
Housing standards	Brick wall and zinc or asbestos roof	Mud and wood poles and combed grass thatch	Mud and uncombed grass thatch
Cash	Always have enough even to lend to others	Enough for the family only	No cash
Percent (%) households per category	**13**	**32**	**55**

2.3.2 Farmers' livelihood activities

Crop and livestock production were perceived as the most important livelihood activities by farmers in all wealth categories. Crop production was ranked high in terms of importance because it is necessary for both subsistence and cash income. In terms of cash income, livestock was also ranked high by farmers in all wealth categories (Table 2.3). Livestock types mentioned as key cash income generators include cattle, goats, sheep and chickens depending on wealth category. Households without cattle and goats earn cash from selling chickens, ducks and domesticated guinea fowls. Farmers argued that crop production was also important in terms of cash income (Table 2.3), as cash crops can be grown and sold. They could also earn cash through value addition to crops such as sorghum, pearl and finger millet. These cereal grains can be used to brew beer, which has higher returns than to grain. Livestock was ranked higher in terms of cash generation than crop production where markets were available with good prices. There were other activities which are normally seasonal and generally depend on the availability of inputs. Brick molding and vegetable production, for example, were said to be done during the dry season when there is less labor competition and also when water is available. Other off-farm activities such as arts and crafts, hired labor and petty trading also contributed to cash income (Table 2.3). Most activities were done by farmers from all wealth categories whereas some activities were group specific (Table 2.3).

Table 2.3 Activities performed by farmers in different wealth categories for their livelihoods for cash income in order of importance

Activity	Contribution to cash income (1,2,3)*	Wealth category
Crop production	1	All categories
Livestock production	1.5	All categories
Vegetable gardens	2	All categories
Brick molding	2	Average and poor
Buying and selling vegetables	3	Average
Brewing beer	3	Average
Building and thatching	3	All categories but mainly those who are qualified
Cutting and selling thatching grass	3	Average and poor
Arts and crafts	3	Average and poor (with skills)
Hired labor	3	Poor

* 1 = high, 2 = average, 3 = low

The three most important livelihood activities (crop and livestock production and vegetable gardening) mentioned by farmers in terms of cash generation were ranked (Figure 2.2). In terms of cash income, about 58% of the respondents in the average group ranked crop production highest as compared to 27% and 32% in the better-off and poor categories, respectively. More farmers in the better-off category ranked livestock production as very high compared to the other two wealth groups. About 43%, 37% and 39% of the farmers in the better-off, average and poor categories, respectively, ranked vegetable gardening as very important in terms of cash income.

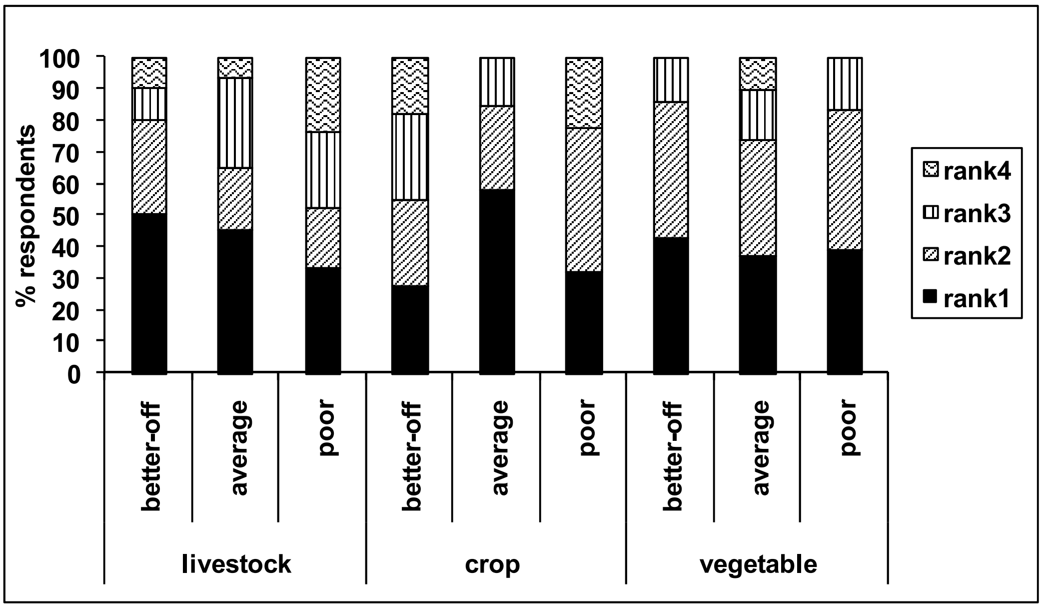

Figure 2.2 Importance in terms of cash income of crop and livestock production and vegetable gardening. rank1= very high, rank2 = moderately high, rank3 = moderately low and rank4 = low

2.3.3 Importance of crop and livestock production for subsistence

Although a number of livelihood activities were performed by smallholder farmers, crop production was ranked highest in terms of subsistence (Figure 2.3). About 84% of the respondents in the average wealth category ranked crop production as highest, while 8 % ranked it second and 8% third. About 40% of the farmers in the better-off category ranked livestock production highest, as compared to 27% and 21% in the average and poor category, respectively. Vegetable production for subsistence was ranked high by a larger portion of farmers in the poor category as compared to the better-off and average farmers. About 47% of the respondents in the poor wealth category perceived vegetable production as very important as compared to 30% and 17% in the better-off and average categories, respectively. Farmers argued that livelihood activities such as crop and vegetable production could be done by all farmers even if they did not have draft power animals. Technologies such as no-till or planting basins could be employed. Farmers without draft power animals could always work as hired labor and get cattle or donkeys to plough their fields in return.

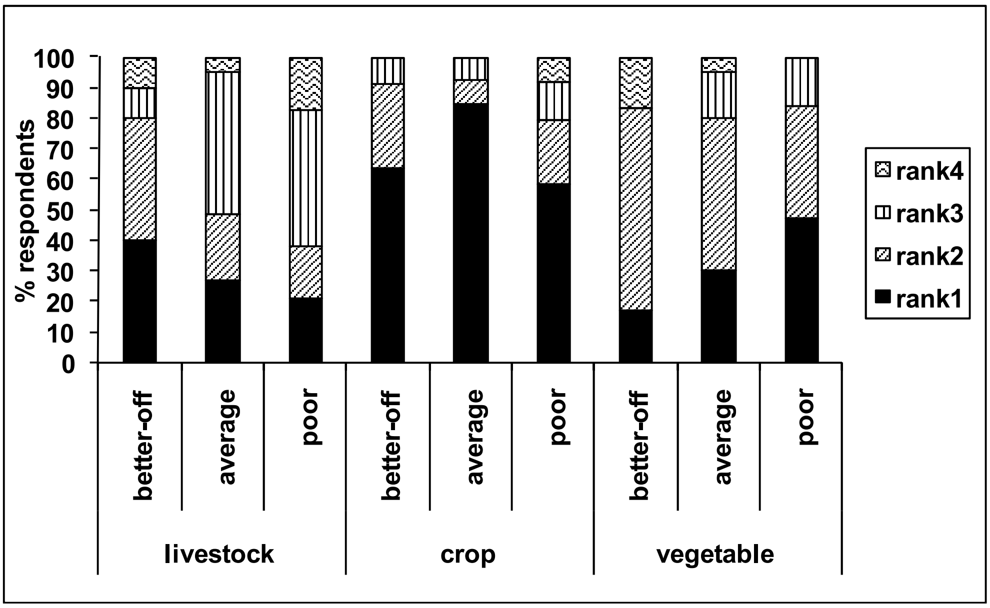

Figure 2.3 Importance in terms of subsistence of crop and livestock production and vegetable gardening. rank1= very high, rank2 = moderately high, rank3 = moderately low and rank4 = low.

2.3.4 Crop production and land holding

There were no significant differences ($p<0.05$) in cropland size across the three wealth categories. Total cultivated area for the growing season 2007/08 was 3.6, 3.2 and 2.5 ha for the better-off, average and poor farmers, respectively. Total cropping land owned by the different farmers was 4.8, 3.8 and 3.2 ha for the better-off, average and poor farmers, respectively. Different types of crops were grown by the different farmers and included cereal crops (maize, sorghum and millet), legumes (groundnuts, cowpeas, bambaranuts and sugar beans) and also cash crops (cotton, sunflower and sugarcane). The crops were grown on varying sizes of land area. Cereals were grown on larger pieces of cultivated land than other crops (Figure 2.4). On average cereal crops were grown on about 76% of the total cultivated area across all farmer wealth categories. Of all cereal crops, maize occupied the largest share of cultivated area. Maize was grown on about 66% of the total cultivated area across all farmer wealth categories. Groundnuts occupied the largest share of cultivated area compared to the other legume crops and were grown on about 9.7%, 9.7% and 6.0% of total crop area by the better-off, average and poor farmers, respectively.

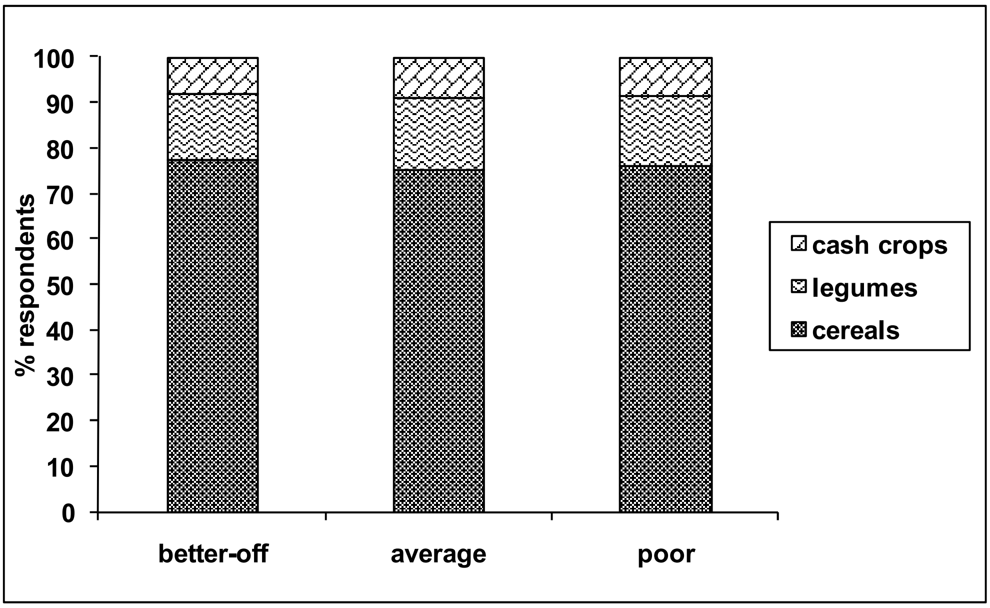

Figure 2.4 Percentage of cultivated area for different crop types across three farmer wealth categories.

2.3.5 Use of crop residues

Most farmers owned several pieces of land, which together make up on average 3.9 ha. Irrespective of the wealth category, most farmers own at least one homestead field. Depending on the available labor and other facilities, some farmers irrespective of wealth category own more than two or three pieces of land that are more than 500 m from their homesteads. Crop residues (CRs) from the different crops are mainly left in the fields for livestock to graze or are carried and stored for dry season feed. About 61% of the respondents in the better-off category cut and carry crop residues for cattle compared to 60% and 42% in the average and poor categories, respectively (Figure 2.5). About 8% the of farmers from the poor category used crop residues for mulching, while 4% and 3% from the average and poor group, respectively, cut and carry CRs for goats. Crop residues used for mulching and soil fertility improvement were said to be beneficial to farmers with well-fenced fields as a protection against free grazing.

Crop residues were cut and carried in varying percentages from the fields (Figure 2.6). About 28%, 36% and 17% of the respondents who cut and carry crop residues in the better-off, average and poor category collected about 75 to 100% from the fields. Crop residues from maize mainly constituted the bulk of the total collected CRs.

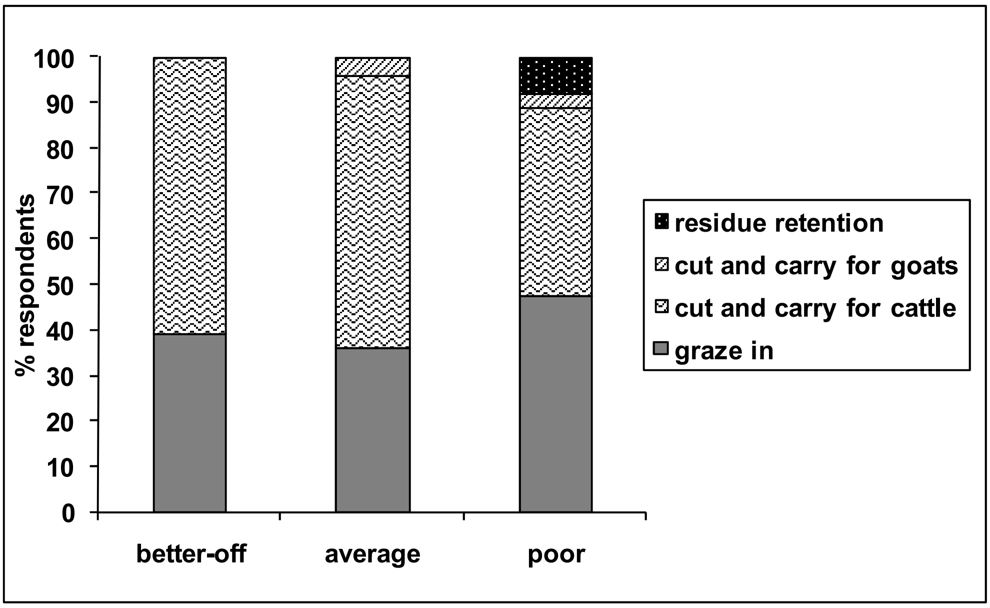

Figure 2.5 Use of crop residues by farmers from different wealth categories.

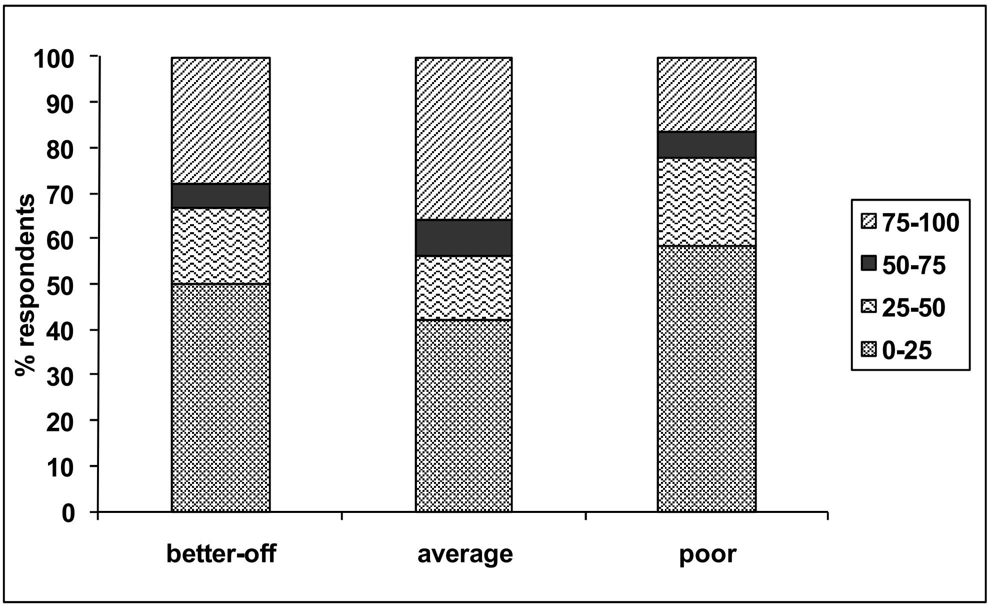

Figure 2.6 Percentage of crop residues collected from the fields by farmers from different wealth categories.

2.3.6 Livestock holdings

All livestock types were considered to be important by the farmers irrespective of wealth category. A substantial amount of products and services were obtained from cattle and goats and to a lesser extent from donkeys and poultry. Attention was given mainly to cattle in terms of health, feed and water needs. Cattle and goat herds are dominated by breeding females. Cattle breeding females are important to farmers as they are multi-purpose animals. They can be used as draft power animals, for milk production, and for reproduction, which will increase the herd size. There were intra- and inter-category variations in terms of livestock holdings. The better-off group had the highest numbers of all livestock types (Figure 2.7). The better-off category owned about 50% of the total livestock whilst they constituted a minority group that was approximately 17% of the total case study farmers. To better understand the distribution of livestock among the different wealth categories, different types of livestock[1] were converted into tropical livestock units (TLU). Regarding livestock holdings 18, 50 and 36 interviewed farmers were in the better-off, average and poor wealth categories, respectively. In terms of TLU per household, the poor group had the lowest indices (Figure 2.8). The better-off had 19.6 TLU per household, while the average and the poor had 6.8 and 2.8, respectively.

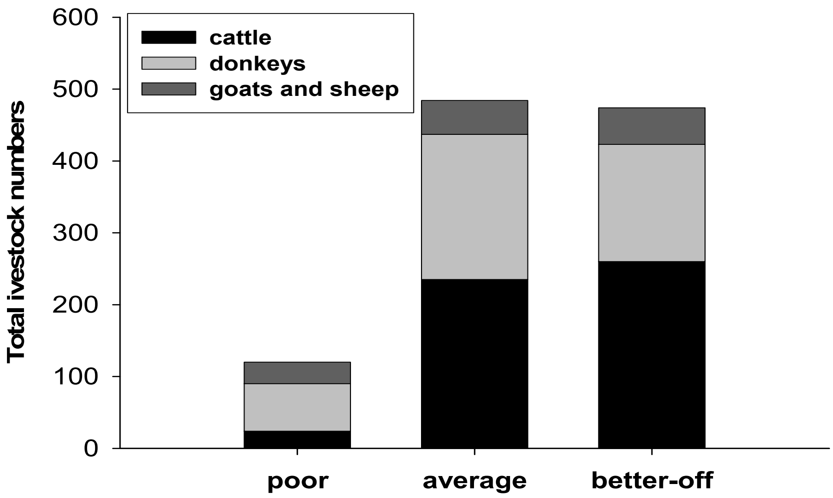

Figure 2.7 Total livestock holdings across wealth categories (Poor farmers n= 38; average farmers n= 50 and better-off farmers n= 18).

[1] Conversion factor of 0.25 for goats and sheep, 0.68 for donkeys and 1.1 for cattle

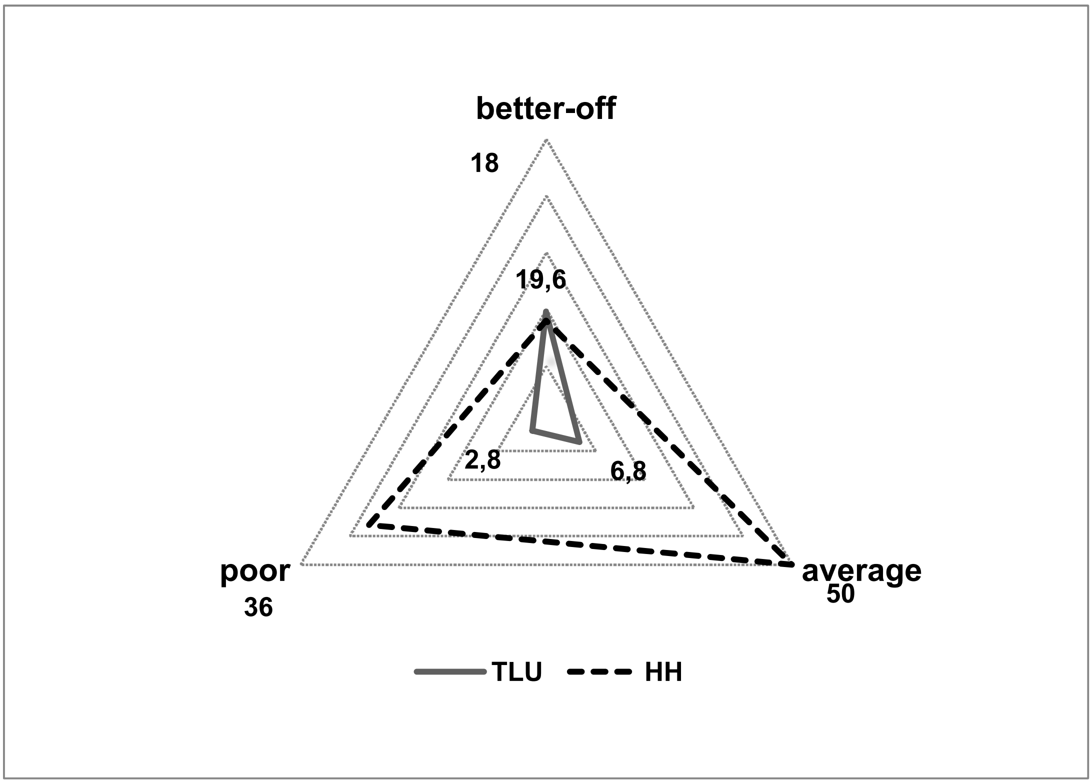

Figure 2.8 Distribution of livestock units across different wealth categories. TLU = tropical livestock unit and HH = household.

2.3.7 Livestock inflows and outflows

Irrespective of farmer wealth category, the major inflow route for both cattle and goats was birth. More than 90% of the cattle and goats kept on-farm were from births, while less than 10% were obtained through purchasing and or as gifts. Reasons for purchasing cattle or goats were mainly to increase herd size or for improved breeding purposes. Major outflows occurred through deaths, which were responsible for 93% and 91% of total cattle and goat losses, respectively, across all farmer wealth categories (Figure 2.9 a-b). Other causes of cattle and goats outflows such as stolen, strayed and home consumption were also mentioned by farmers, but they represented a minor share in total livestock losses. On average, outflows through sales were 3% and 7% for cattle and goats, respectively.

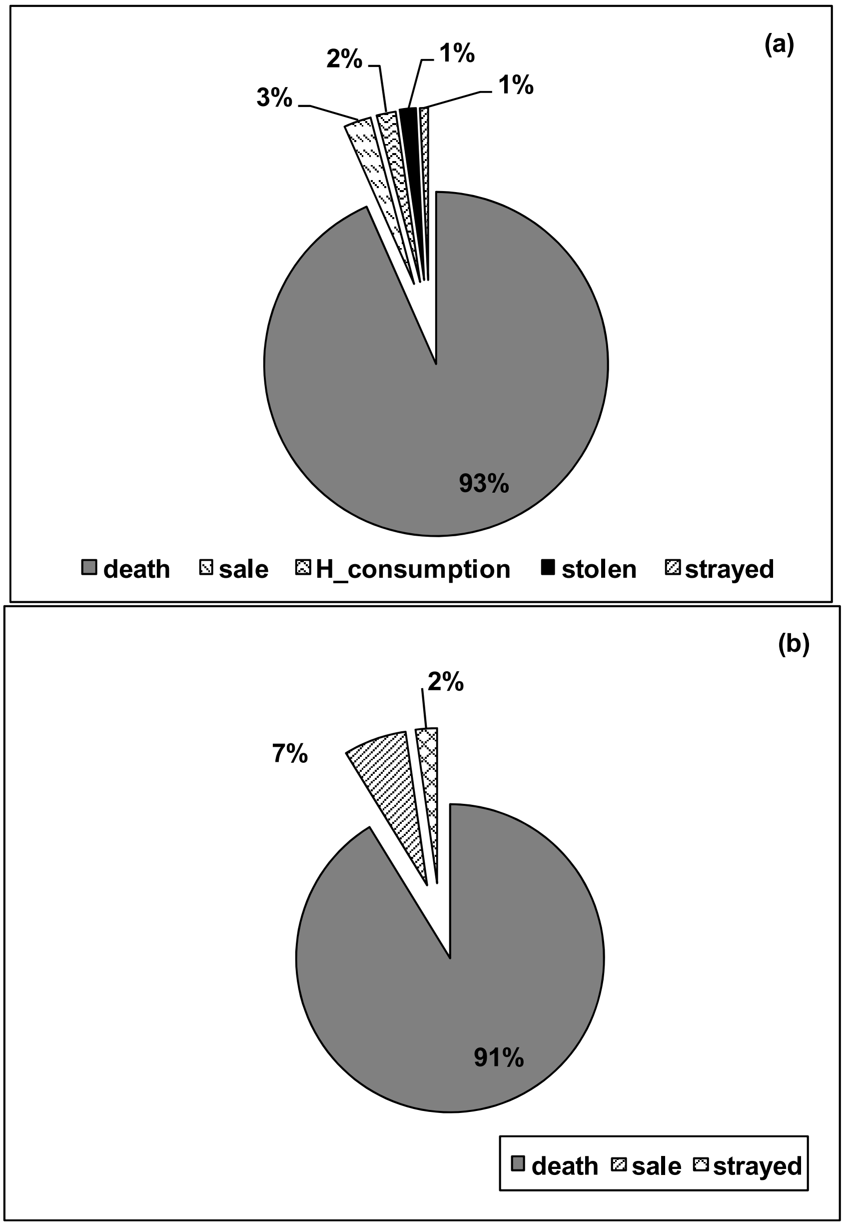

Figure 2.9 Share of different types of outflows for (a) cattle and (b) goats. H_consumption = household consumption.

2.3.8 Causes of livestock deaths and the affected animal types

Causes of cattle and goat mortality mentioned by farmers included poisoning, diseases and others (Figure 2.10 a-b). The main causes in cattle were tick-related diseases. These represented about 77%, 85% and 71% of cattle mortality for the better-off, average and poor farmer wealth categories, respectively. For goats, the major causes were also by tick-related diseases and constituted about 96%, 81% and 87% of goat mortality for the better-off, average and poor farmers, respectively.

The types of animals lost through death differed across wealth categories for both cattle and goats (Figure 2.11 a-b). The better-off farmers had high losses of about 70% and 40%, while the average farmers had losses of about 47% and 49% of total losses from cattle and goat breeding females, respectively. Farmers in the poor category had high losses of more than 55% from goat kids as compared to the average and better-off categories who had 32% and 0% losses, respectively. Cattle male intact losses were also reported to be higher by respondents from the poor farmers as compared to the other in the average and better-off categories (Figure 2.11 a-b).

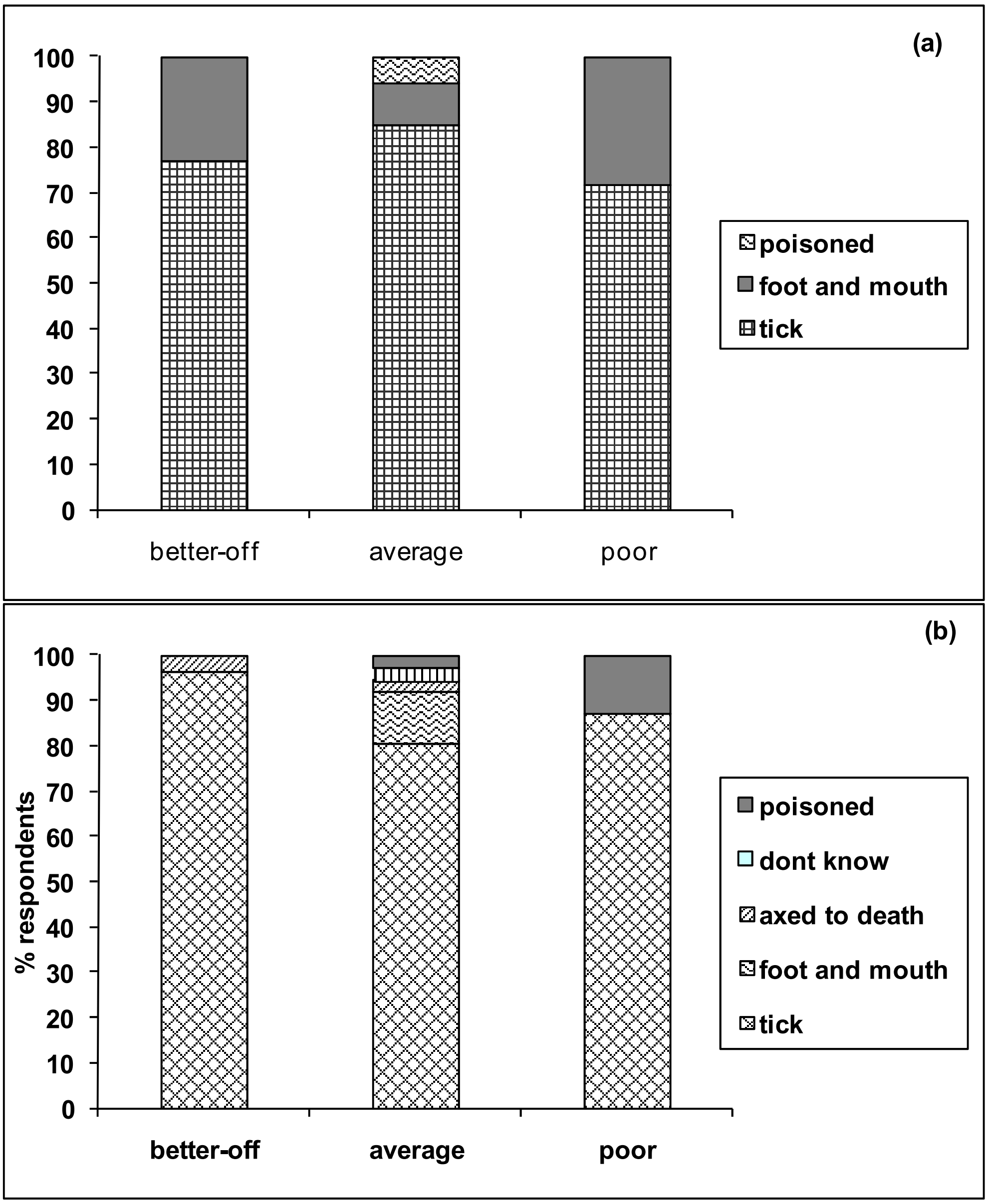

Figure 2.10 Causes of livestock mortalities across farmer wealth categories (a) cattle and (b) goats.

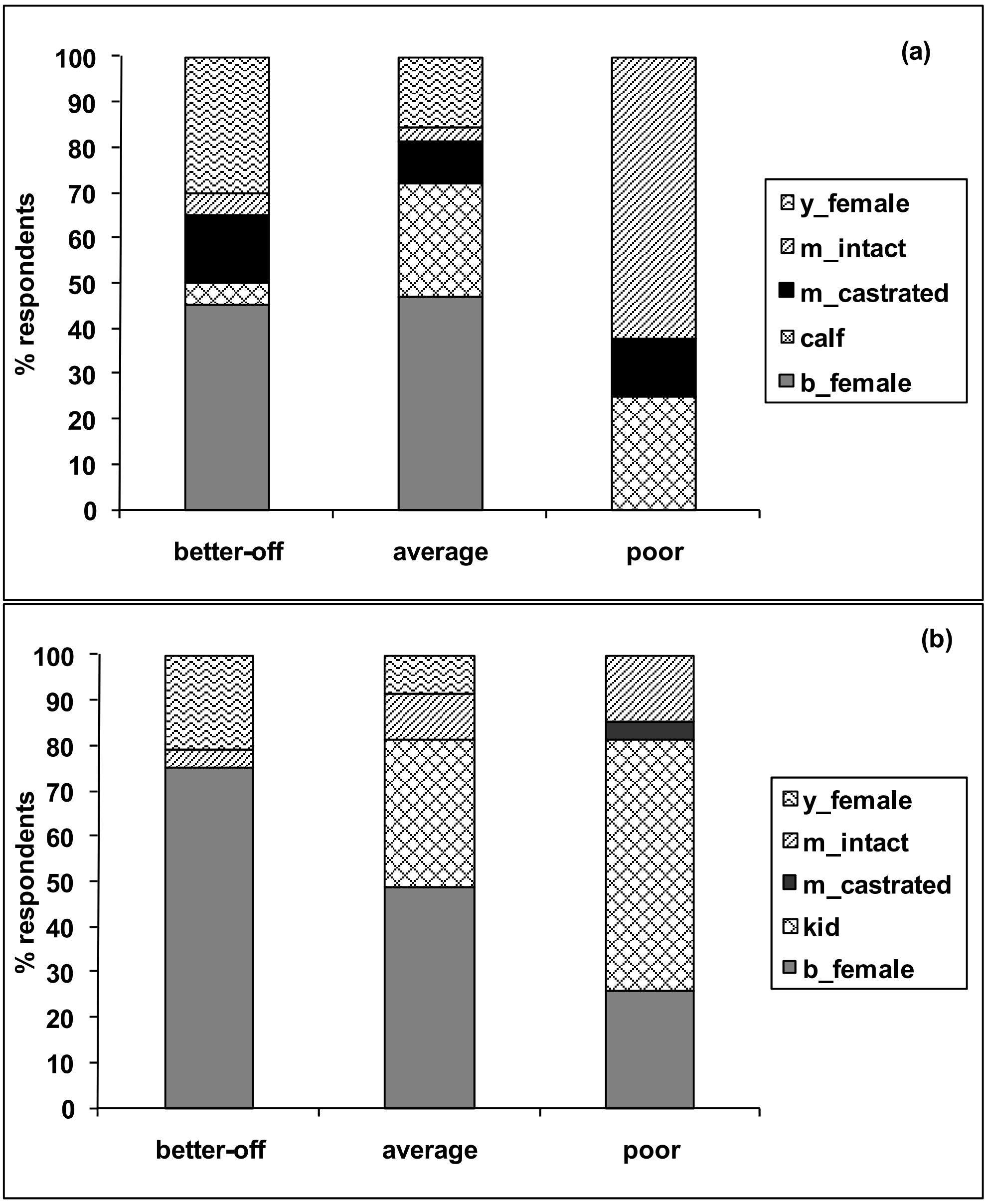

Figure 2.11 Share of animal types in total deaths of (a) cattle and (b) goats for different wealth categories. b_female = breeding females, y_female = young females, m_intact = males intact, m_castrated = males castrated

In general, livestock outflow through mortality was higher for the poor farmer category as compared to the other two wealth categories (Table 2.4). Cattle mortality rates were 29.2, 16.2 and 11.5% for the poor, average and better-off categories, respectively. On the other hand, goat mortality rates were 47.0, 33.2 and 17.2% for the poor, average and better-off categories, respectively. Wealth had no effect on off-take[2] rates for both cattle and goats. Off-take rates for cattle were generally lower than those for goats, while mortality rates were higher for goats than for cattle, across all farmer wealth categories.

Table 2.4 Cattle and goats holdings and outflows across different wealth categories

Wealth category	**n**	**Total holdings**		**Mortality rates (%)**		**Off-take rates (%)**	
		Cattle	Goats	Cattle	Goats	Cattle	Goats
Better-off	18	260	163	11.5	17.2	0.4	0.0
Average	50	235	202	16.2	33.2	0.9	3.0
Poor	36	24	66	29.2	47.0	0.0	6.1

2.3.9 Livestock production constraints and mitigation strategies

Diseases: The major constraint for cattle production in the smallholder farming systems is the high animal mortality through diseases. Prevalent diseases were tick related. Acaricides that are used to control ticks were said to be unavailable on local markets and very expensive hence farmers used unconventional methods such as brushing animals with used car engine oil or picking ticks manually from the animals.

Dry season feed: Feed shortage during the dry season in terms of quantity and quality was another factor affecting livestock productivity. A few farmers used crop residues to mitigate feed shortages. Residues used were from maize and were fed untreated, thus they were of low nutritional value to animals.

Drinking water: Water constraints were prevalent during the dry season, where animals had to walk long distances of up to 14 km per day for drinking purposes. The condition of the animal worsened as energy from the limited feed was wasted by walking. The water points were limited and large numbers of animals used the same points. As a result, high chances of spreading diseases, especially those which are water-borne, and land degradation are common problems. Farmers let their cattle drink once every 2 days and gave goats recycled water from their homestead

[2] Off-take is the number of animals (cattle and goats) sold by farmers during the study period from October 2007 to September 2008

2.3.10 Crop production constraints

Major constraints in crop production were poor soil fertility, lack of improved seed, and lack of draft power. Farmers did not have access to inorganic fertilizers. They also did not use livestock manure intensively due to labor shortages, as some crop fields were more than 1 km from the homesteads. The farmers also noted that the manure especially from cattle “does not have enough food for the crops”, and caused high weed infestation in crop fields if not composted prior to application. The other constraint for crop production was lack of labor for weeding. Crop-land is no longer available for new fields in the case study area; hence farming often takes place on the same field without soil fertility amendments, thus resulting in very low crop yields.

2.3.11 Crop and livestock markets

Farmers emphasized that market facilities for cattle and for crops such as maize and cotton are not adequately developed. For the other crops, e.g. sunflower and legumes, there were hardly any markets as the yield of these crops were very low. Markets for goats did not exist at all, and farmers depended on farm gate sales or took their animals to the nearest business center. These informal markets were said to be poorly coordinated and put farmers at a disadvantage, as they cannot negotiate for better prices. Due to low off-take rates, low numbers of livestock were sold, which hinders competition, as most market actors stay out of the business because of high transaction costs. Farmers also lacked market information such as sale dates, quality and quantity requirements.

2.3.12 Policies and institutions governing crop and livestock production

Crop and livestock production is also influenced by policy and institutional factors that act at the individual farm, local community and country level. Social and commercial services were available, but most were poorly equipped and therefore offered limited services to farmers. Government services such as schools, clinics and extension services were not fully functional. Related infrastructure such as roads and dip tanks as well as electricity and telecommunications were in a bad state and offered limited services.

2.4 Discussion and conclusions

The main determinants of wealth in smallholder farming systems in Nkayi district are livestock (mainly cattle) numbers and level of crop (mainly maize) production. Crop and livestock production are the main livelihood activities for subsistence and cash income. On-farm production by smallholder farmers for subsistence and cash income has been reported in other studies (Homann et al. 2007). However, the present study differs in the sense that it presents the relationship between farmer wealth categories and on-farm crop and livestock production and constraints. This helps to better identify potential interventions targeted to individual farmers wealth categories. An important constraint, for example, was livestock mortality rates which differed across wealth categories (Table 2.4). The better-off farmers had lower mortality rates for both cattle and goats as compared to the other wealth categories. This can be attributed to the fact that better-off farmers have better opportunities to obtain vaccines to prevent animal deaths and to treat their animals. However improvements can be made if such farmers are supported by information on how to effectively use the available vaccines. A study conducted by Homann et al. (2007) shows that most farmers in communal areas of Zimbabwe were often unable to identify diseases and causes or to determine appropriate treatment.

Although mortality rates differed across wealth categories, in general the rates are very high for both goats and cattle. The low availability of tick controlling acaricides and their high prices mean that most farmers are not able to treat their livestock. Reducing mortality in both cattle and goats can substantially benefit farmers in terms of cash, products and services such as manure and draft power, which can be used to improve crop production. Information on mortality and off-take rates can be used in livestock simulation models to quantify beneficial products across wealth categories. The effects of reduced mortality rates have been simulated using the DynMod[3] model and results show that decreasing mortality rate by about 10% could improve livestock productivity by at least 20% (Nkomboni et al in prep.).

In regard to livestock off-take and wealth category, there was no clear relationship, and this can be attributed to the fact that farmers mainly keep livestock for

[3] DynMod; A tool for demographic projections of tropical livestock populations under Microsoft Excel (Lenoff, 2007)

other purposes rather than for commercial purposes. Average off-take rates were higher for goats than those of cattle across wealth categories. This reflects that farmers keep cattle mainly for draft power and milk, while goats are for cash income (Chapter 4). Goats showed the highest mortality rates across all wealth categories as compared to cattle. Greater benefits can be achieved by reducing mortality rates and increasing off-take rates in goats. Average off-take rates obtained in the current study are lower than the 3% reported by Barret (1991) for smallholder farmers in the humid areas of Zimbabwe. However, most farmers have no incentives to invest in goat management, possibly due to low returns on their investments, and they possibly do not see the commercial potential of goats (Homann et al. 2007). These are some of the production constraints. They are complex in nature and require investments beyond technological interventions, hence integrated measures taking on board social, institutional and policy issues are required (Amede et al. 2009).

Feed shortages during the dry season are also one of the constraints on livestock production. Crop residues, mainly maize stover, are used as an adjunct to dry season livestock feed. Maize yield is generally low, which results in low quantities of stover. During the dry season, natural pastures supply about 50% of the feed requirements, while about 40% is expected to be from crop residues (Ngongoni et al. 2006). The amount of available crop residues depends on the quantities produced, collected and preserved for later use. About 40% of the farmers in the current study use crop residues for in situ grazing and about 50% collect less than 25% of the total amount produced. Improving feed resources during the dry season can be beneficial to livestock, as more than 70% of calving occurs during this period (Ngongoni et al. 2006). Improving feed can build up disease resistance and increase milk production, and this will improve the cow and the calf body conditions. Grass and legume pasture hay can also be used to alleviate the dry season feed shortages.

Although pests and diseases take their toll, widespread water shortages, low soil fertility and feed shortages are the most pervasive constraints on crop and livestock production. These constraints are within farmers’ capacity for mitigation. Crop production can be improved by judicious addition of crop residues and/ or organic manure to the soils. Livestock feed shortages can be alleviated by inclusion of high quality forages that can be mixed with other crop residues to increase feed quantity and quality during the dry season. In Zimbabwe leguminous crops such as *Lablab purpureus, Mucuna pruriens, Medicago sativa* and *Cajanus cajan* have been introduced to commercial and communal farmers mostly in the subhumid areas, where productivity was improved through provision of alternative low-cost fertilizers for crop production (Maasdorp and Titterton 1997; Ngongoni et al.2007). Grain legumes are also known to improve soil fertility, but farmers only grow them in small areas due to their high preferential production of cereal staples, lack of quality seeds, disease constraints and lack of output markets (Ncube et al. 2008). In contrast, forage legumes such as mucuna have been tested under smallholder conditions and have been identified as reliable alternatives to reduce continued large-scale use of inorganic fertilizers (Omotayo and Chikwuka 2009). Legume forage production in Nkayi is limited, where only about 1.4% of the farmers grow forages (Homann et al. 2007). Possible reasons for this limited production are lack of access to information and technologies, and the unavailability of labour, seeds and land. In the study area, the average land holding area was 3.9 and about 0.9 ha weedy fallows. The main reason given by smallholder farmers for weed fallowing was soil fertility restoration (Maasdorp et al. 2004). Integrating forage legumes in the current cropping systems is one promising technology that can be used to improve crop production, soil fertility and livestock production.

3 EVALUATION OF WATER PRODUCTIVITY IN SMALLHOLDER CROP-LIVESTOCK PRODUCTION SYSTEMS IN THE SEMI-ARID TROPICS OF ZIMBABWE

3.1 Introduction

About 70% of the world's poor people live in rural areas of developing countries where livelihood options in sections other than agriculture are limited (Molden et al. 2007). For these communities agriculture is essential for their daily food requirements. Currently, the world population is around 6 billion and is projected to increase to 7.8 billion in 2025 (Cai and Rosegrant 2003). Almost all population growth (95%) takes place in the tropical developing countries, and it is also there that the bulk of under nutrition occurs (Rockström et al. 2003). In 2003, 850 million people in the world were food insecure, 60% of them living in South Asia and sub-Saharan Africa (Molden et al. 2007). The climate is changing, affecting temperatures and precipitation patterns. Tropical areas with intense poverty, such as a large part of sub-Saharan Africa, will be most adversely affected by climate change (Molden et al. 2007). In sub-Saharan Africa, about 95% of the agricultural production depends on rainfall, and most farming systems integrate crop and livestock production (Cai and Rosegrant 2003). Rain-fed crop production systems in the semi-arid tropics of Sub-Saharan Africa are characterized by low productivity due to rainfall variability and low soil fertility.

For Zimbabwe in particular, agricultural production is low with major cereal grain yields ranging from 0.5 to 1 t ha^{-1} (Ahmed et al. 1997), milk production averages below 500 kg per lactation, and off-take rates ranging from 1.5 to 3% per annum (Barret 1991; Ngongoni et al. 2006; Mapiye et al. 2009). The economies of semi-arid tropics of Zimbabwe are characterized by gross income and wealth inequalities between and within economic sectors and population groups (Graham 1987 cited in Mpofu 2005). Agricultural production is not an exception to this rule, as large differences in productivity levels can be observed between large-scale commercial and smallholder farmers (Mpofu 2005). As opposed to the low productivity values for smallholders mentioned above, milk production among commercial farmers in Zimbabwe ranges from 4000 kg to 6000 kg per lactation, and off-take ranges from 13 to 23 % per annum (Barret 1991; Ngongoni et al. 2006). Maize production on large commercial farms ranges from 4 to 5 t ha^{-1} under rain-fed conditions (Rohrbach 1989). Improving livestock breeds adapted to communal area conditions and improved nutrition and livestock husbandry have been reported to increase overall livestock production under smallholder farming systems (Mpofu 2005; Ngongoni et al. 2006). Low livestock and crop production under smallholder farms are mainly caused by suboptimal performance related to management aspects rather than to low physical potential (Rockström et al. 2003).

There is growing concern that in dry areas water will be a limiting factor for increasing food production, hence it must be used more efficiently (Comprehensive Assessment of Water Management in Agriculture 2007). Increases in crop production in the past two decades in Zimbabwe have resulted largely from an expansion in area rather than from increases in land and labour productivity (FAO 2006). As there is a limit to new land for agriculture production, it is important to increase agricultural productivity through raised yields per unit soil and water (Rockström et al. 2003). Water productivity is generally defined as crop production per cubic meter of water consumption, including 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from systems) for irrigated areas (Cai and Rosegrant 2003). Recently, it has been recognized that livestock feed production depletes large amounts of global fresh water, and consequently, the concept of increasing livestock water productivity (LWP) is emerging (Peden et al. 2007). LWP is a new concept that is theoretically defined as the ratio of livestock products and services to the amount of water used in producing these products and services (Peden et al. 2007).

In the Comprehensive Assessment of Water Management in Agriculture (2007) it is highlighted that there is great scope for improving productivity in rain-fed areas and for expanding irrigated areas in sub-Saharan Africa. The potential of crop and livestock production in Zimbabwe is evidenced on the commercial farms with good management and access to resources and inputs, which play an important role in production. Targeting smallholder farmers particularly in largely rain-fed areas offers the best chances for poverty reduction in developing countries, as these farmers have the greatest unexploited potential to directly influence land and water management in current production systems (Comprehensive Assessment of Water Management in Agriculture 2007).

Crop and livestock productivity in smallholder farming systems is low, and there are several factors that affect production, e.g., biophysical and socio-economic. These conditions affect farmers' decisions on management and even technology adoption. Management decisions by smallholder farmers are usually affected by access to key resources such as labour, land, farm implements and traction power (Holden et al. 2004 cited in Haileselassie et al. 2009). Differences in access to key resources affect overall crop and livestock production and have implications for financial and physical water productivity. For beneficial interventions to be developed, the prevailing conditions in these farming systems must be understood. Also, for improvements to be effected there is a need for determining the starting point. The specific objective of the study was to explore the magnitude of physical crop and financial livestock water productivity indices in smallholder farming systems in Nkayi District as affected by household resources ownership.

3.2 Materials and methods

3.2.1 Biophysical Characteristics of the study area

The study was done in Nkayi district in northwest Zimbabwe. The district is located between 19° 00′ South and 28° 20′ East. Crop production is rain-fed, and average annual rainfall ranges from 450-650 mm. Rainfall is erratic with drought frequencies of 1 in every 5 years (Rockström et al. 2003). Longterm average maximum and minimum temperatures are 26.9 and 13.4 °C, respectively (Figure 3.1). The soils vary from inherently infertile deep Kalahari sands, which are mainly nitrogen and phosphorus deficient, to clay and clay loams that are also nutrient deficient due to continuous cropping without soil replenishment. Farmers use a mono-cereal-cropping system with addition of low amounts of inorganic and organic soil amendments. Natural pasture provides the basic feed for livestock, and biomass availability is seasonal. During the wet season feed quantity and quality is appreciable while during the dry season there is low biomass of poor quality. The natural pastures are mainly composed of miombo woodlands and sweet veldt grass species (Homann et al. 2007).

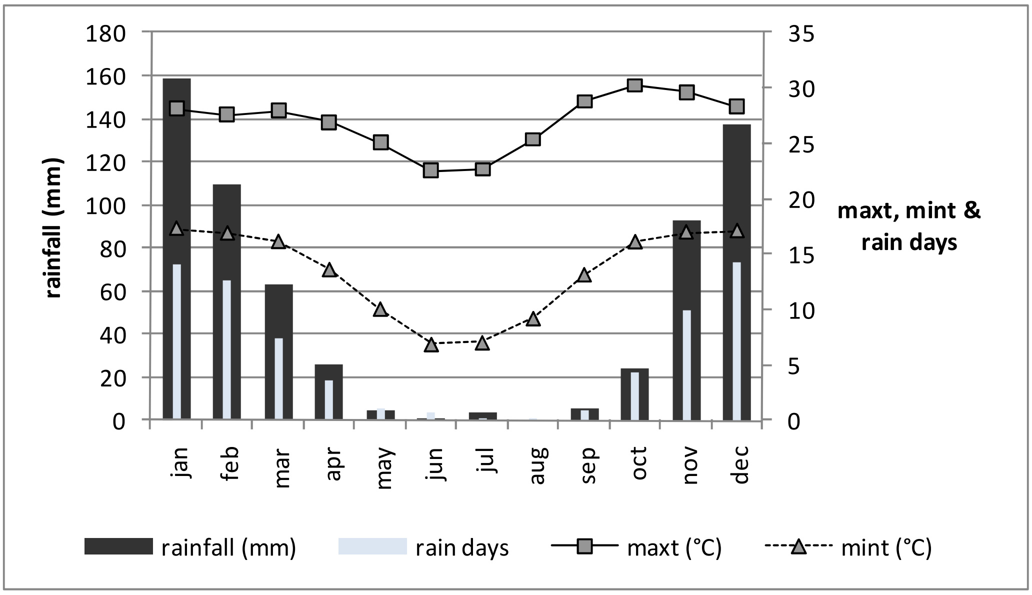

Figure 3.1 Long term (1902 – 2002) mean monthly records of climatic data from Nkayi district Meteorological station.

3.2.2 Farming systems

Mixed farming systems that integrate crops and livestock are predominant in the area. Major cereal crops are maize (*Zea mays*), sorghum (*Sorghum bicolor*) and to a lesser extent pearl millet (*Pennisetum glaucum)* and finger millet (*Eleusine coracana)*. Crops also include legumes such as groundnuts (*Arachis hypogea)*, cowpeas (*Vigna Anguiculata)* and cash crops such as cotton (*Gossypium spp)* and sunflower (*Helianthus annuus*). Maize grain yields range from less than 500 kg ha^{-1} to about 1500 kg ha^{-1} (Ahmed et al.1997) Farmers manage different livestock species in varying ratios. Cattle (*Bos taurus*), goats (*Capra hircus*), donkeys (*Equus asinus*) and sheep (*Ovis aries)* are the major livestock species. Livestock play an important role in these farming systems as they offer opportunities for risk coping, farm diversification and intensification and provide significant livelihood benefits to the rural poor (Williams et al. 2002). Animals are kept to compliment cropping activities through the provision of manure for soil fertility maintenance, draft power for cultivation, transport, cash and food (Williams et al. 2002; Powell et al. 2004).

3.2.3 Household survey and participatory rural appraisals

The study was conducted in four wards, and 104 farmers were interviewed during surveys. During participatory rural appraisal (PRA) meetings, about 40 to 45 farmers from each ward attended. Data collection was done in two phases. The first phase consisted of a household survey together with PRAs conducted in September 2008 and the second of household surveys in October 2008. The first phase was to get general household information such as land and livestock holdings, reasons for keeping different types of livestock and wealth ranking. The second phase was to get further information on crop production technologies, constraints and opportunities in crop and livestock production. Information on livestock feeding strategies and beneficial products and services was also collected. Land use, rangeland management and degradation were also discussed.

In addition to information on general household information, soil samples were also collected from 9 farmers per ward to assess the soil fertility status in the study area. For this, data from surveys and PRAs regarding wealth ranking were analysed and used to randomly select the farmers. The farmers were divided into three categories according to livestock, and in particular, cattle ownership, which is related closely to wealth status (poor, average, better-off). The better-off farmers were those with more than 9 heads cattle, average farmers had cattle numbers which ranged from 4 to 8 and, the poor had a maximum of 2 or none. There were three farmers per category, and each farmer was treated as a replicate. Soil samples were collected at the beginning of the season 2008-2009 for chemical analyses. Three replicates were collected and combined according to depth increments to obtain composite soil samples per site. Sampling was done to a depth of 90 cm using soil sampling tubes of 5 cm diameter. Samples were divided into depth increments of 0-15, 15-30, 30-60 and 60-90 cm. They were dried at 60 °C, sieved through a 2 mm sieve and analysed for nitrates, phosphates, organic carbon, total N and P and pH following the procedures in Okalebo et al (1993). Available soil N and P were calculated using the following equation by Dalgliesh and Foale (1998):

$$Available\ N\ or\ P\ = \frac{N\ or\ P\ conc\ x\ BD}{Soil\ layer\ thickness\ x\ 10} \tag{3.1}$$

where N or P conc = nitrogen or phosphorus concentration and BD = bulk density.

Milk production was also assessed over a one-year period from January to December 2009. It was recorded by the farmers on a daily basis and measured using measuring cylinders that had been provided for this purpose.

3.2.4 Rain-fed crop and livestock water productivity

The evaluation of the WP of crops took into account all crop outputs and partitioned the water flows into water going into grain production, which was factored into crop WP and water going into feed production which was factored into LWP (Descheemaeker et al, in prep). To achieve this, an approach based on harvesting index (HI) and feed use factors (FU) was used to partition crop evapotranspiration (ET) into ET for grain and residues. Feed use factors of 0.7 and 1.0 were used for cereal and legume crop residues, respectively (Descheemaeker et al, in prep). These reflect that animals consume a certain percentage of crop residues depending on quality and palatability. The considered crops were those cultivated by farmers during the cropping season 2007-2008 and used for both food and feed, these were maize, sorghum, groundnuts and cowpeas. Water productivity was evaluated using evapotranspiration during the growing period of 90 days. To estimate ET of the different crops, reference evapotranspiration (ET_o) was calculated using the FAO Penman-Monteith equation (FAO,1998). The calculated ET_o was then multiplied by the crop coefficients Kc (FAO 1998) to obtain ET for the different crops:

$$ETg,i = ETc,i \cdot HI \tag{3.2}$$

$$ETfres,i = ETc,i \cdot (1 - HIi) \cdot FUres,i \tag{3.3}$$

where $ET_{g,i}$ is the ET to produce the grain of crop i, $ET_{fres,i}$ the ET to produce the residues of crop i used as feed, $ET_{c,i}$ the overall ET for crop i, HI_i the harvesting index of crop i, and $FU_{res,i}$ the feed-use factor of the residues of crop i.

$$CWP = \frac{\sum_i Og,i}{\sum_i ETg,i} \tag{3.4}$$

where CWP is crop water productivity at household level, Og,i the grain output of the crop i, ETg,i the water depleted by evapotranspiration to produce grain of crop i [m3].

Livestock products and services used to calculate LWP at household level were milk, meat, manure and draft power (traction and transport). The size of total grazing land and village arable land was estimated using images from LANDSAT TM, which were used to assess land-cover changes in the study area (Chirima et al, in prep). The images were used to delineate grazing land from crop land. The household share of grazing land was estimated using the factor of tropical livestock units per hectare (TLU ha^{-1}) of the communal grazing area. Water depleted to produce the tradable outputs was calculated using the grazing area per TLU which was estimated to be (0.3 TLU ha^{-1}) (ICRISAT survey, 2008). The evapotranspiration value for the grazing area was assumed to be 3.8 mm day^{-1} (Singh et al. 2005) with a biomass growth period of 120 days.

Livestock mortality is one of the major draw-backs in livestock water productivity. Amede et al (2009) emphasize that all efforts to improve LWP will be undermined by high mortality rates, as the animal that dies takes all the water it has utilized directly and indirectly during its lifespan with it. The effects of livestock mortality were included in the evaluation to quantify the extent to which LWP can be reduced by mortality rates across the different farmer wealth categories. As quantifying LWP deals with different types of outputs and services, their financial market value was used to unify them using the US$ (Haileslassie et al. 2009; Descheemaeker et al, in prep). At the time of the survey the local currency was not being used, farmers were using the South African Rand which was worth 0.1 US$ during the survey period. Procedures outlined in Haileslassie et al. (2009) and Descheemaeker et al (in prep.) were used to quantify LWP at household level:

$$LWP = \frac{\sum_j Ols,j \cdot Pls,j}{\sum_j ETf,k} \tag{3.5}$$

where Ols,j is the livestock output j [several different units], Pls,j the local market price of the output j [US$/unit], and ETf,k the water depleted by evapotranspiration to produce feed type k [m3].

3.2.5 Livestock beneficial outputs

In this study, tradable livestock products and services reported by the farmers in Nkayi district were considered when quantifying LWP; these included milk, manure, draft and off-take. Livestock off-take was defined as the number of animals (cattle and goats) sold by the farmers during the period from October 2007 to September 2008. To quantify livestock outputs, different assessment methods were employed. Total livestock holdings (cattle, donkeys, goats and sheep) were converted to TLU using a conversion factor of 0.25 for goats and sheep (from here on referred to as goats) and 0.68 for donkeys (FAO 1991; Nengomasha and Jele 1985). The average liveweight of the cattle measured on-farm was used to estimate the TLU factor. The value used was 300 kg, and hence the conversion factor of 1.1 for cattle was employed. To calculate draft power, each draft animal (oxen and donkeys) was assumed to work for 37.5 days a year (on-farm data) while cows were assumed to work 6 days a year (Barret 1991) for ploughing and transportation. Data on the daily hiring cost of draft animals were collected from the sample households. Total annual milk production was determined based on the number of cows and calves, lactation period of 157 days (Barret 1991; Ngongoni et al. 2006) and daily average milk production collected on-farm from sample households, where milk production was monitored over one year. The prize per litre of milk was obtained from local markets. Manure quantity was estimated using the daily dry weight production of 2.4 kg for goats and 3.3 kg of dung day^{-1} TLU^{-1} for cattle (Haileslassie et al. 2009). The fertilizer value in terms of nitrogen (N), phosphorus (P) and potassium (K) was determined using nutrient concentrations in manure (Chivenge et al. 2004; Masikati, 2006) and local fertilizer prices were used to determine the cost (in US$) of the nutrients in question. The cost of N, P and K was US$ 0.70, 0.74 and 0.74 kg^{-1}, respectively. Ammonium nitrate and compound-D fertilizers were used to estimate the costs of N, P and K in manure using their different proportions in the fertilizers.

3.3 Results

3.3.1 Reasons for keeping livestock

The reasons for keeping livestock varied among farmer wealth category and livestock type (Figure 3.2 a-c). Across all wealth categories, cattle were kept mainly for draft followed by milk and manure. Cash income was mentioned by about 50% of the better-off farmers as a third reason for keeping cattle as compared to 26 and 25% in the average and poor wealth categories, respectively. Other reasons mentioned were meat and social security. The primary reason for keeping goats was meat for family consumption followed by manure and cash income. For goats, milk was another reason that was considered more by the farmers in the poor category as compared to the other two wealth categories. Donkeys were mainly kept for draft, cash income and social security in all three categories.

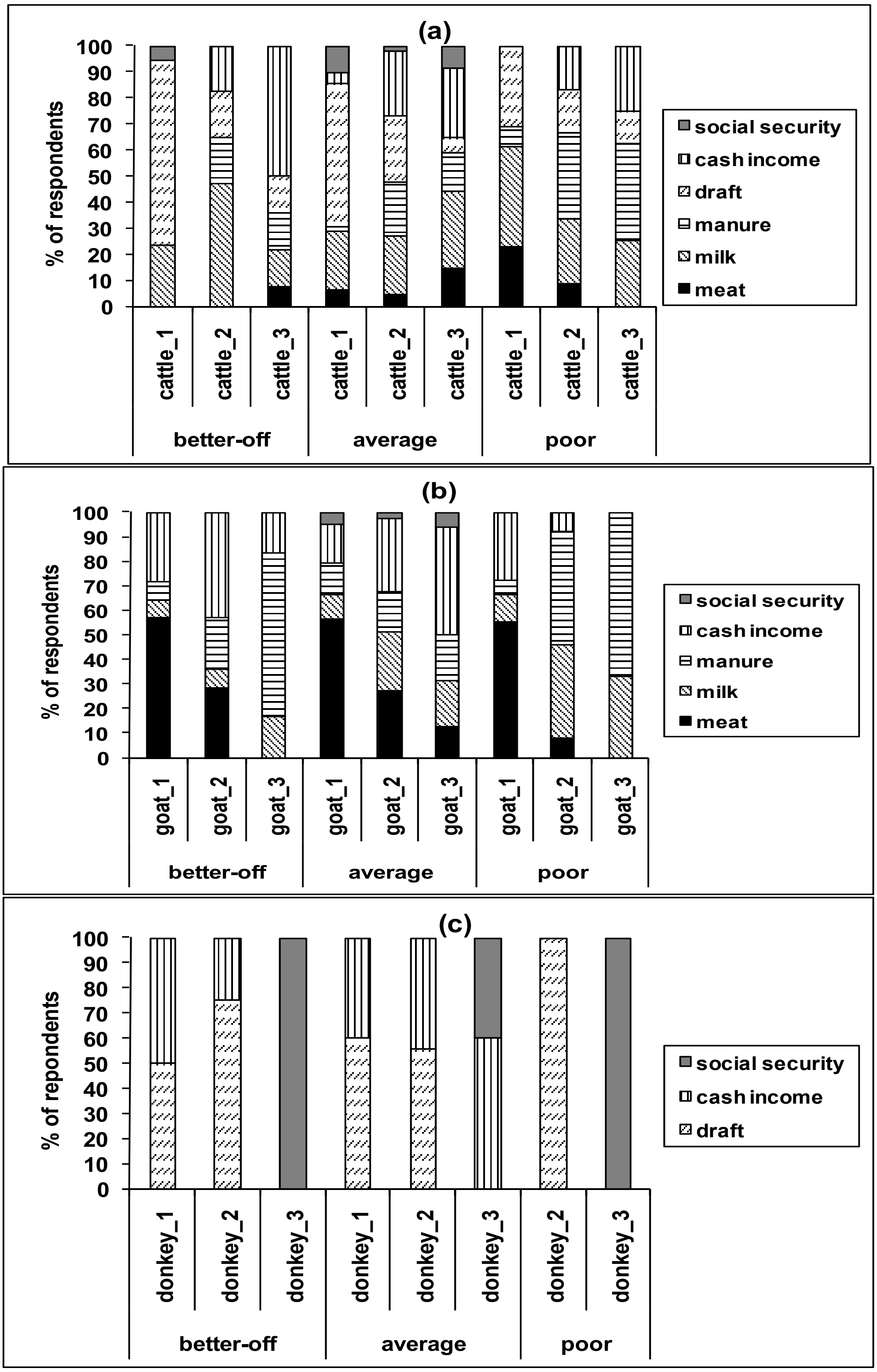

Figure 3.2 a-c Reasons for keeping different types of livestock (a) cattle, (b) goats and (c) donkeys as mentioned first, second and third indicated by (1, 2 and 3) by farmers in different wealth categories, better-off, average and poor.

3.3.2 Variability of access to key production resources

Soils from better-off farmers had on average higher nutrient contents as compared to the other two wealth categories (Table 3.1). There were also high variations across farms in available N ranging from 0.001 kg ha^{-1} to 13.16 kg ha^{-1}. Average available N in the different wealth categories was 5.02, 9.65 and 13.48 kg ha^{-1} in the poor, average and better-off categories, respectively. There were no significant differences between pH and bulk density (BD) values of soils from the different farmers. Average pH was 5.5 with minimum and maximum values of 3.9 and 7.3, respectively. Average BD was 1.66 g cm^{-3} with minimum and maximum values of 1.29 and 1.84 g cm^{-3}, respectively.

Variability in key resource holdings were observed among the different wealth categories (Table 3.2). There were significant differences ($p < 0.05$) between TLU holdings per household in all wealth categories. Farmers in the better-off, average and poor category owned 19.6, 6.8 and 1.5 TLU, respectively. Overall average livestock holdings were 7.4, 1.3 and 0.99 TLU for cattle, goats and donkeys, respectively. Cattle are the major type of livestock in the area and constitute 75 % of the total livestock TLU, whereas goats and donkeys constitute only 14 % and 11 % of total TLU in the area, respectively. There were no significant differences between means of crop area owned by the different farmers. Average crop area for the sample households was 3.9 ha, with the famers in the better-off category having the largest crop area (4.8 ha). Intra-category variations in land holding were observed with minimum and maximum crop area ownership ranging from 1 to 11 ha per household in the better-off and from 1 to 8 ha in the poor category.

Table 3.1 Soil fertility status of case study farmers at the beginning of the cropping season 2008/2009. Significance between means is based on standard error values, at P=0.05 OC = organic carbon; Total P = total phosphorus; Total N = total nitrogen., comparison was made between wealth groups within the system.

Wealth category	**n**	**OC (%)**	**Total P (%)**	**Available P (kg ha^{-1})**	**Total N (%)**	**Available N (kg ha^{-1})**
Better-off	12	0.40±0.04	0.014±0.02	0.48±0.07	0.03±0.00	13.48±1.70
Average	12	0.37±0.03	0.010±0.00	0.30±0.05	0.05±0.01	9.65±1.47
Poor	12	0.34±0.02	0.012±0.00	0.36±0.08	0.03±0.00	5.02±1.45
Weighted mean		0.37±0.02	0.012±0.00	0.38±0.03	0.04±0.00	9.87± 0.96
Minimum		0.02	0.00	0.00	0.00	0.00
Maximum		1.24	0.04	2.36	0.25	49.95

3.3.3 Crop production

Crop yield and water depleted to produce grain and crop residues varied across all wealth categories and across the different crops (Table 3.3). Grain yield was less than 200 kg ha^{-1} across all crop types and wealth categories. Significant differences between crop grain yields were only observed for sorghum. Water depleted for crop production was less in the better-off category as compared to the other two categories, although there were no significant differences between the means.

Table 3.2 Land and livestock holdings from survey farms in four wards in Nkayi district (2008)., means followed by the same letter are not significantly different at P= 0.05,

		On-farm key resources				
Wealth category	n	Total crop area (ha)	Average total TLU	Cattle (TLU)	Goats and sheep (TLU)	Donkeys (TLU)
Better-off	18	4.8 ± 0.7a	19.6 ±2.5a	15.9 ± 2.0a	2.3 ±0.4a	1.9 ± 0.4a
Average	50	3.8 ± 0.3a	6.8 ±0.4b	5.2 ± 0.3b	1.0 ± 0.1b	0.6 ± 0.1b
Poor	36	3.2 ± 0.3a	2.8 ±0.3c	1.7 ± 0.2c	0.5 ± 0.1c	0.6 ± 0.1c
Weighted mean	**104**	**3.9 ± 2.5**	**9.7**±0.7	**7.6 ± 7.2**	**1.3 ± 1.3**	**0.99 ± 1.5**

Table 3.3 Harvesting index (HI), feed use factor (FU), grain yield and water depleted as evapotranspiration for different crop types in Nkayi district (2008).

Crops	HI	FU*	Grain yield (kg ha^{-1})	Water depleted for grain production (mm)	Water depleted for feed production (mm)	Grain yield (kg ha^{-1})	Water depleted for grain production (mm)	Water depleted for feed production (mm)	Grain yield (kg ha^{-1})	Water depleted for grain production (mm)	Water depleted for feed production (mm)
				Better-off			***Average***			***poor***	
Maize	0.3	0.7	121.6±35	132.8±23	217.0±38	106.9±21	189.5±27	309.7±45	69.6±27	192.5±25	314.4±41
Sorghum	0.3	0.7	124.0±51	65.7±33	107.4±54	19.7±9	124.2±57	202.9±94	10.3±6	154.6±73	252.6±12
Groundnuts	0.4	1	2.5±3	12.5±9	18.8±13	77.9±26	151.4±64	227.1±96	19.2±11	103.9±57	155.8±85
Cowpeas	0.3	1	--	--	--	5.1±5	81.7±56	190.7±13	--	--	--

* FU = feed use factor, values were adopted from (Descheemaeker et al., in prep.)

3.3.4 Livestock products and services

There were significant differences ($p<0.05$) on total value of all the livestock products and services (Table 3.4) across the three farmer wealth categories. The better-off farmers had the highest value of all livestock products and services as compared to the other two farmer categories. The total value of all beneficial livestock outputs at household level among wealth categories was US$ 5005, 1716 and 358 year^{-1} for the better-off, average and poor respectively. Value of manure, in the form of N, P and K fertilizer, had the highest share of products and services, followed by draft power and milk. Proceeds from livestock off-take contributed the least to the total value of products and services. Livestock productivity showed a decrease in productivity with decreasing access to key resources. The poor farmers achieved lower productivity compared to the average and better-off farmers.

3.3.5 Livestock and crop water productivity

Livestock and crop water productivity of the farm households was determined and compared among wealth categories (Table 3.5). The results show varied indices of crop and livestock water productivity across farmer wealth categories. There were significant differences in LWP values between the different wealth groups. The poor farmers had the lowest value of 0.012 US$ m^{-3}, while the better-off and average categories had 0.021 and 0.021 US$ m^{-3}, respectively. Livestock mortality substantially reduced LWP among the poor farmers (0.012 to 0.007 US$ m^{-3}). Generally, mortality reduced overall mean LWP from 0.017 to 0.014 US$ m^{-3}. There were no significant differences between all CWP values across all wealth categories except for sorghum. Average CWP was 0.04 kg m^{-3} for maize, sorghum and groundnuts. Although there were no significant differences, marked differences in CWP values were observed between the better-off and the other two wealth categories. In general, the better-off had higher outputs per unit of water depleted

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Table 3.4 Livestock productivity at household level of the survey farms across 3 wealth categories in Nkayi district (2008). Significance between means is based on standard error value, means followed by the same letter are not significantly different at P= 0.05

Wealth category	**Livestock products and services (US\$ $year^{-1}$)**					
	n	Total livestock productivity (US\$ $year^{-1}$)	Draft	Fertilizer	Milk	Off-take
Better-off	18	4973 ± 663a	903 ± 128a	3482 ± 427a	517 ± 138a	72 ± 9a
Average	50	1706 ± 86b	287 ± 30b	1191 ± 57b	204 ± 28b	24 ± 1b
Poor	36	356 ± 60c	110 ± 27c	235 ± 38c	6 ± 6c	4 ± 1c
Weighted mean	**104**	**214 ± 74.5**	**34.0 ± 27.8**	**141.8 ±65.7**	**35.5 ± 33.1**	**3.5 ± 1.6**

Table 3.5 Livestock and crop water productivity across wealth categories in four wards in Nkayi district. LWP = livestock water productivity, LWP mortality = livestock water productivity adjusted for mortality rate, WP = physical crop water productivity. Significance between means is based on standard error value, means followed by the same letter are not significantly different at P= 0.05

Wealth category		**Livestock water productivity**		**Crop water productivity**			
	n	LWP (US\$ m^{-3})	LWP mortality (US\$ m^{-3})	maize WP (kg m^{-3})	sorghum WP (kg m^{-3})	groundnut WP (kg m^{-3})	cowpea WP (kg m^{-3})
Better-off	18	0.021 ± 0.0a	0.019 ± 0.0a	0.13 ± 0.0a	0.14 ± 0.1a	0.00 ± 0.0a	--
Average	50	0.021 ± 0.0a	0.016 ± 0.0b	0.11 ± 0.0a	0.02 ± 0.0b	0.06 ± 0.0a	0.01 ± 0.0b
Poor	36	0.012 ± 0.0b	0.008 ± 0.0c	0.07 ± 0.0a	0.01 ± 0.0c	0.01 ± 0.0a	--
Weighted mean		**0.017 ± 0.6**	**0.014 ± 0.1**	**0.04 ± 0.0**	**0.04 ± 0.0**	**0.04 ± 0.0**	**0.00 ± 0.0**

3.4 Discussion and conclusion

3.4.1 Access to key resources

One of the central factors affecting farm management decisions is the farmer's power of decision making (Holden et al. 2004 cited in Haileslassie et al. 2009). The power of decision making is closely related to access to key resources such as land and livestock holding among others (Haileslassie et al. 2009). In Nkayi district, the livelihood activities ranked highest by farmers are crop and livestock production, which are mainly for subsistence and cash income. Livestock play an important role in these farming systems, as they provide several beneficial products to the farmers. Farmers gave the reasons for keeping livestock as draft power, manure, and milk and cash income, among others. Cattle and donkeys were mainly kept by farmers for draft power, while goats were kept mainly for meat for family consumption. Manure was not mentioned as one of the most important reasons for livestock holding. This can be attributed to labour shortages, as some of the crop fields are far from the homesteads. This also reflects a weakness in crop-livestock interactions, which can be strengthened in these farming systems. Cereal production was very low (< 200 kg ha^{-1}), while average grain water productivity was 0.04 kg m^{-3} across the three wealth categories. This could be attributed to severe flooding in December 2007 and January 2008, followed by extreme dry weather conditions during the growing season (USAID, Situation report #1 2008). Rainfall in December 2007 was 53% higher than the longterm average of 138 mm, while in January it was 83% higher than the longterm average of 158 mm (Nkayi Meteorology Station). In the smallholder farming systems of sub-Saharan Africa cereal grain yield ranges from 500 to 1000 kg ha^{-1} (Ahmed et al.1997), while water productivity ranges from 0.04 to 0.1 kg m^{-3}, (Rockström et al. 2003).

Crop production is determined mainly by land and livestock holding. In this study, there were no significant differences between land holding across wealth groups, but there were significant differences with regard to livestock holding. On average the better-off farmers constitute less than 20% of the households in the area, but they own more than 50% of the livestock. Average total N and P in the soils was 0.04% and 0.012%, respectively. Soil nutrients were higher on the better-off farms than on the other two farmer wealth categories. This can be attributed to the high numbers of livestock, hence higher quantities of available manure and also draft power to carry the manure to the fields. Soil organic carbon ranged from 0.34% to 0.40% across farmer wealth categories. Soil OC is the backbone of soil organic matter, and affects soil quality as it is a reservoir of nutrients and positively influences soil properties such as cation exchange capacity, aggregation, soil bulk density, microbial activity and soil tilth (Coulter et al. 2009). In general low soil OC, N and P may hinder fertilizer response. Soil testing is important for fertilizer recommendations and determination of possible nutrient deficiencies. For example, for a yield of 1000 kg ha^{-1} of sorghum grain with 7% protein content, about 20 kg of N applied to the soil is necessary (Dalgliesh and Foale 1998). Average available soil N was about 9.8 kg ha^{-1}, thus farmers would need to apply a considerable amount of additional organic or inorganic fertilizer N to attain a yield of at least 1000 kg ha^{-1}. The study shows that access to resources such as manure is not proportional to utilization as evidenced by the low soil fertility status especially in the better-off wealth category.

3.4.2 Livestock and crop water productivity

In terms of livestock numbers, the better-off farmers owned significantly more livestock as compared to the other two wealth groups. Both LWP and CWP were low, ranging from 0.012 to 0.021 US\$ m^{-3} and from 0.01 to 0.14 kg m^{-3}, respectively across the wealth categories. With respect to total livestock productivity values, the better-off farmers had the highest compared to the other two wealth categories. Most of the livestock benefits were obtained from manure, mostly because of the large numbers of livestock of the better-off farmers. Offtake and milk production were low in the area. Average offtake was 0.3%, while milk production was 1.3 l day^{-1} cow^{-1} across the wealth categories. This could be attributed to the fact that farmers do not milk their cows completely, as they leave some milk for the calf. Farmers also stated that most of their cows have 1 or 2 teats that do not function due to damage by ticks. Low offtake rates could be attributed to the fact that smallholder farmers are subsistence oriented rather than commercially oriented. This is also demonstrated in the reasons for keeping livestock, which are primarily draft power, milk, security, manure and to a lesser extent for cash income. Livestock productivity values in the study area were lower than those reported by Descheemaeker et al. (in prep) for smallholder farmers in Ethiopia, which are 0.09 US\$ m^{-3}. Data on crop and livestock productivity at farm scale are useful to assess entry points for improved management and production. To improve production, a combination of crop and livestock productivity enhancement strategies need to be employed. The following interventions can be used as entry points to improve productivity in the study area:

1. Smallholder farmers own more than 50% of the cattle in Zimbabwe (Barret 1991) but offtake only ranges from 0.8 to 3%, whereas on the commercial farms it ranges from 15 to 23% (Barret 1991; Mpofu 2005). Livestock mortality in the area is also high, i.e. average mortality rates are 17 and 28% for cattle and goats, respectively. If these losses can be converted into beneficial products, LWP can be substantially increased in these systems.
2. The highest value from livestock comes from manure. Increasing manure quality can increase total on-farm productivity directly by increasing manure value and indirectly by improving crop productivity. Increased crop production will enhance supplementary feed especially during the dry season. This will also enhance crop-livestock interactions, which are currently not very strong. Improvement can be achieved by inclusion of forage crops in current systems, which can improve crop productivity through biological nitrogen fixation and livestock productivity through improved availability of high quality feed.
3. Farmers keep cattle mainly for draft power followed by milk, security, manure and to a lesser extent for cash income. As opposed to cattle, goats are mainly kept for meat and cash income. Improving goat production in the studied systems can be used as an entry point for reorientation of the farmers from subsistence to commercial farming. Development from subsistence farming to commercially oriented livestock production has been an objective in the region for a long time, but has had very little success (Homann et al. 2007). There is also a need for policies and institutions that can provide incentives for smallholder farmers aiming at food security and commercialization. While improved production and marketing can help many smallholder farmers to escape the poverty trap, the farmers also need to produce the right product and to have access to information and appropriate support services (Homann et al. 2007).

4 BIOMASS PRODUCTION OF FORAGE LEGUME CROPS IN SMALLHOLDER FARMING SYSTEMS IN THE SEMI-ARID AREAS OF ZIMBABWE: APSIM MODEL PARAMETERIZATION

4.1 Introduction

The use of forage crops for improving crop and livestock productivity and improving degraded rangelands has been researched for a number of years in Zimbabwe (Maasdorp and Titterton 1997; Mugabe et al 2004; Whitbread et al. 2004; Ngongoni et al. 2007). Different types of forages, which include forage legumes and grasses and leguminous shrubs, have been introduced in Zimbabwe, mainly to commercial and communal farmers in the sub-humid areas, with the aim to provide high quality feed and improve crop and livestock productivity (Masana et al. 1997; Mupangwa et al. 1997; Ngongoni et al. 2007). However there is a lack of information on the potential production and contribution of cultivated forages to crop and livestock production systems of smallholder farmers in the semi-arid areas of Zimbabwe. The semi-arid areas of Zimbabwe are considered suitable for extensive livestock production but less than 3% of farmers in these areas grow forage crops (Homann et al. 2007) despite frequent if not yearly experiences of feed shortages especially during the dry season. Possible reasons for limited forage crop production are lack of knowledge, access to information and technologies, and availability of seeds (Homann et al. 2007). Livestock offer opportunities for risk coping, farm diversification and intensification and provide significant benefits to smallholder farmers in semi-arid areas (Williams et al. 2002). The ability of livestock systems to continuously provide these functions and services is greatly affected by inadequate availability of feeds. Feed shortages are further exacerbated by the reduction in rangeland, as more arable land is being cleared for cropping activities, and by severe overstocking and poor husbandry (Hargreaves et al. 2004).

Cultivated forages, especially legumes, have the potential to increase the productivity of cereal crops (through biological nitrogen fixation) and livestock (through improved availability of high quality feed especially during the dry season) in smallholder farming systems (Nyoka et al. 2004). However, potential beneficial effects of cultivated forages in the semi-arid areas of Zimbabwe have not yet been fully explored. Understanding the effects of forage legumes in mixed crop-livestock systems through field experiments is extremely costly and time consuming. Well proven crop models can be useful as evaluation tools for lengthy and expensive field experiments (Steduto et al. 2009). There are a number of models that have been developed to simulate crop growth processes such as CERES-MAIZE, APSIM, DSSAT, and CENTURY, among others, and each has its capabilities and limitations (Loewer 1998; Matthews 2002). The Agriculture Production Systems Simulator (APSIM) has been developed to simulate biophysical processes in farming systems in relation to the economic and ecological outcomes of management practices in the face of climate risk (McCown et al. 1996; Keating et al. 2003). APSIM development resulted from a need for a tool that could help farmers, researchers and decision makers to predict crop production in relation to climate, genotype, soil and management factors while addressing the long-term changes in the resource base (Keating et al. 2003).

APSIM has been an accessible tool for over 20 years for developing intervention strategies targeted at smallholder farmers in Africa under a wide range of management systems and conditions (Whitbread et al. 2010). In the Sahel zone for example, Akponikpe` et al. (2010) investigated millet response to nitrogen (N) in a view to establish recommendations for N application rates that are better adapted to smallholder farmers. Delve et al. (2009) evaluated phosphorus response in annual crops in Eastern and Western Kenya. Ncube et al. (2008) assessed the impact of grain legumes on cereal crops grown in rotation in nutrient-deficient systems in Zimbabwe. Shamudzarira (2002) evaluated the effects of mucuna green manure technologies on maize yield in southern Africa. Although models are considered to be sufficiently refined to provide an alternative to field experimentation, it is always important to test their credibility. The credibility of a model is usually tested by its predictive performance against measured data sets (Probert 2007), thus the need for short-term experiments that can provide sufficient details for the intended model application. The aims of this study were therefore to (i) assess potential biomass production of cultivated forages under smallholder farming systems, and (ii) evaluate the predictive performance and robustness of APSIM by comparing the simulated maize grain and stover and mucuna biomass yield and the nitrogen content in stover and mucuna biomass, against field and laboratory measurements.

4.2 Materials and methods

4.2.1 Study sites

Field experiments were carried out at the International Research Institute in the Semi-Arid Tropics (ICRISAT), Matopos Research Station and also in Nkayi district. All field experiments took place during the cropping season 2008-2009. The Matopos Research Station is located between 20° 25′ south and 28° 24′ east while Nkayi district lies between 19° 00′ south and 28° 20′ east. Both sites are characterized by semi-arid climatic conditions with annual rainfall that ranges between 450 and 650 mm. Long-term average maximum and minimum temperatures are 26.9 and 13.4 °C, respectively, for Nkayi and for Matopos 26.6 and 13.2 °C, respectively.

On-station experiments were done on clay and sandy soils. The clay soil located at the main Matopos experimental site is an imperfectly drained vertisol derived from igneous or metamorphic rocks and classified as Pelli-Eutric Vertisol (World reference base 1998) (Moyo 2001). The sandy is located at the Lucydale experimental site, 18 km from the main experimental site. The soils are shallow to moderately deep, well drained fersiallitic sand derived from granite and classified as Eutric Arenosol (World reference base, 1998) (Moyo 2001).

On-farm experiments were carried out in the smallholder farming systems in Nkayi district. Predominant soils in the area are Arenosols (World reference base 1998) (FAO, 2006). The experiments were done on 36 farms. Mixed farming systems which integrate crops and livestock are predominant in the area (Chapter 2 and 3).

4.2.2 Experimental layout

On-station experiments were established in a complete randomized block design on each site. The experimental crops were maize (*Zea mays*) *cvv.* SC04, sorghum (S*orghum bicolor*) *cvv.* SV4, mucuna (*Mucuna pruriens*) *cvv.* Utilis and Lablab (*Lablab purpureus*) *cvv.* Highworth. All crops were grown under three fertility treatments, namely farmer practice (FP), micro-dose (MD), and recommended (RC). In the FP treatment no inorganic or organic fertilizers were applied. In the MD fertility treatment 17 kg N ha^{-1} was applied on maize and 11 kg P ha^{-1} on mucuna and lablab (Twomlow et al. 2008). In the recommended treatment 35 kg N ha^{-1} and 22 kg P ha^{-1} were applied on the cereal crops and mucuna and lablab, respectively (Mhere et al. 2002). Maize and sorghum were planted as sole crops at a spacing of 30 cm x 75 cm on net plot sizes of 60 m^2. Mucuna and lablab were also planted as sole crops at a spacing of 20 cm x 60 cm on net plot sizes of 60 m^2. The N and P fertilizers, which were used were ammonium-nitrate (AN) and single super phosphate (SSP). Single-super-phosphate was banded on planting lines at sowing on 29 November 2008 on the clay soil site and on 12 December 2008 on the sandy soil site. Ammonium-nitrate was spot applied as top dressing on 21 January 2009 and on 22 January 2009 on the clay and sandy soil sites, respectively.

Mucuna and lablab were harvested at flowering (~ 13 weeks after planting WAP) on both sites for biomass and total N and P determination; samples were collected from plot sizes of 4 m^2. Maize was harvested at maturity (~19 WAP) for grain and stover yield and total N and P determination; samples were collected from plot sizes of 14 m^2. Plant material from the net plots was weighed to determine fresh weight, sub-sampled and dried at 70 °C for 48 hours to determine dry matter weight. Mucuna, lablab and maize stover subsamples were ground to pass through a 2-mm sieve and analyzed for total N and P using analytical methods described by (Okalebo et al. 1993. Data from these experiments were used to test the ability of the APSIM model to simulate maize and mucuna yield on different soil types and at varying N rates.

On-farm experiments were established at 36 farms, where 27 were on sandy and 9 on sandy loam soils. The soils had different nutrients contents but across all farms nutrients such as N and P were low (Chapter 3). The main aim of the experiments was to test the potential production of and possible pests and diseases on mucuna and lablab and also to determine farmers' perception of the two forage crops. This was important as the crops were fairly new to the area, and farmers had no knowledge about these crops. It was also important to test the potential of these forage legumes as farmers had expressed that one of the major causes of low livestock productivity was feed shortages in terms of quantity and quality especially during the dry season. Wealth category (mainly determined by cattle ownership) was used as the criteria to randomly select 36 farmers who were involved in surveys in September and October 2008; 12 farmers were selected per wealth category (better-off, average and poor) (Chapter 1).

Maize, sorghum, mucuna and lablab were grown under the FP and MD treatments on all 36 farms. At each site, plots of 6 m x 6 m were laid out randomly in blocks with no on-farm replication. Most farmers (n = 32) managed to plant the experimental plots between 12 and 19 December 2008 with some technical help from hired field assistances. The experiments were researcher designed and managed by farmers. The farmers were responsible for tillage operations and weeding and were helped in the planting and harvesting operations. All procedures for fertilizer application (on legumes at sowing and on cereals approximately 35 DAS) and harvesting of mucuna and lablab were the same as those described for the on-station experiments.

4.2.3 Model description and parameterization

The Agricultural Production Systems Simulator (APSIM) is a modular modeling framework that can be used to simulate complex climate-soil-vegetation management systems (McCown et al. 1996; Keating et al. 2003). To simulate the cases in this study, the APSIM-maize, APSIM-mucuna (Robertson et al. 2004), SOILN2 and SOILWAT2 modules (Probert et al. 1998) were linked within the APSIM version 6.1. The crop modules (APSIM-maize and APSIM-mucuna) simulate on a daily time-step the phenological development, leaf area development, biomass accumulation (above and below ground), grain yield, N fixation by legumes, water and N uptake. Crop growth is determined by climatic conditions (temperature, rainfall, radiation) where potential biomass growth is a function of the intercepted radiation and radiation use efficiency.

The crop modules have 11 crop stages and 10 phases (time between stages). Commencement of each stage is determined by accumulation of thermal time except during the sowing to germination period which is driven by soil moisture. Between the stage of emergence and flowering the calculated daily thermal time is reduced when water or N stress occurs resulting in delayed phenology. Both the maize and mucuna modules require specific parameters related to crop phenology. The cultivars used in the experiments have set parameters in APSIM. Maize cultivar SC401 is an early maturing hybrid from Zimbabwe and has been extensively used by a number of researchers to simulate maize production in Africa (Probert 2007; Delve et al. 2009). The mucuna_gen in APSIM developed by Robetson et al (2004) is a typical cultivar, which is grown under smallholder conditions in southern Africa. Testing of mucuna in APSIM has only been done in Africa, hence Robertson et al (2004) states that APSIM-Mucuna can be used with high confidence in southern Africa.

The SOILWAT2 module uses a multi-layer, cascading approach for the water balance. Soil water characteristics are described in terms of volumetric water content at saturation (SAT), drained upper limit (DUL), and lower limit (LL15) of plant extractable soil water. Estimates of SAT, DUL and LL15 were obtained for each experimental site from soil water profiles measured during the 2002-2004 cropping season (Masikati 2006; Ncube et al. 2008) for the sandy soil site and during the 2004-2006 cropping season (Mupangwa 2009) for the clay soil site. In the SOILWAT2 module, run-off is estimated using the United States Department of Agriculture run-off curve number (Probert 2007). The partitioning of rainfall between infiltration and runoff is determined primarily by the curve number (cn2-bare). The cn2_bare parameter (0-100) is an input to the model and describes the runoff propensity of the soil under bare soil conditions for the given rainfall environment and land configurations, i.e., the higher the number, the higher the simulated runoff. Soil curve number (cn2-bare) was set to 85 similar to that used by Probert (2007). The soil evaporation is determined by the first stage (U) and second stage (CONA) evaporation. The evaporation and CONA parameters (Ritchie 1972) were held constant at 6 mm and 3.5 mm day-$^{0.5}$ respectively, i.e., they were adjusted to closely relate to the values used by Ncube et al. (2008) for soils at the same study site and Probert (2007) on a sandy soil in the same tropical environment. Two soil water descriptions for the two study sites are presented in Table 4.1 and 4.2. The plant available water capacity (PAWC) for the sandy soil site was 59 mm (0-70 cm) while for the clay soil 73 mm (0-90 cm)

The SOILN2 module has three soil organic matter pools (FOM, BIOM and HUM) with transformations considered in each soil layer. The FOM is the fresh organic matter pool, which is partitioned into the BIOM and HUM pools. The BIOM is the more labile, soil microbial products, whilst the HUM comprises the remaining soil organic matter. The flows between the different pools are calculated in terms of carbon; the corresponding N flows depends on the C:N ratio of the receiving pool. The C:N ratios of the various pools are assumed to be constant through time; C:N for BIOM is specified in the INI file, whilst the C:N of HUM is derived from the C:N ratio of the soil that is the input. Starting conditions of simulations were also defined for percent organic carbon (OC) and nitrate-nitrogen (NO3-N) measured at the beginning of the cropping season 2008-2009 (Table 4.1 and 4.2).

Table 4.1 Soil water, NO3-N and OC input parameters for the experimental sandy soil in APSIM v 6.1

Parameter	Soil layer (cm)					
	0-20	20-30	30-40	40-50	50-60	60-70
Airdry (mm/mm)	0.03	0.07	0.09	0.09	0.09	0.09
Crop_LL(mm/mm)	0.04	0.07	0.13	0.13	0.18	0.22
DUL (mm/mm)	0.14	0.15	0.20	0.20	0.22	0.24
SAT (mm/mm)	0.44	0.45	0.45	0.40	0.40	0.38
BD (g/cc)	1.43	1.42	1.42	1.55	1.50	1.61
OC (%)	0.60	0.51	0.50	0.40	0.40	0.40
NO_3-N (ppm)	1.28	0.81	0.49	0.67	0.27	0.17

Table 4.2 Soil water, NO3-N and OC input parameters for the experimental clay soil in APSIM v 6.1

Parameter	Soil layer (cm)					
	0-10	10-20	20-30	30-40	40-60	60-90
Airdry (mm/mm)	0.10	0.12	0.18	0.23	0.24	0.27
Crop_LL(mm/mm)	0.15	0.16	0.18	0.23	0.24	0.27
DUL (mm/mm)	0.28	0.30	0.30	0.30	0.30	0.32
SAT (mm/mm)	0.38	0.40	0.40	0.40	0.40	0.42
BD (g/cc)	1.50	1.46	1.45	1.45	1.45	1.40
OC (%)	1.00	0.90	0.70	0.60	0.50	0.40
NO_3-N (ppm)	1.94	1.61	2.09	0.80	1.35	0.25

4.2.4 Climate data and crop management

Daily rainfall was recorded on the experimental sites, while temperature and radiation data were obtained from NASA (http://earth-www.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?agroclim@larc.nasa.gov). The meteorological data from November 2008 to June 2009 were used for model evaluation. Maize cultivar SC04 and mucuna cultivar mucuna_gen were sown on 29 November and on 12 December 2008 on the clay and sandy soils, respectively. The fertility treatments for the maize crops were the farmer practice (FP), micro-dose (MD), and recommended (RC). Mucuna was not simulated under the different fertilizer treatments as the APSIM-mucuna module is not P responsive as this is currently under development (Robertson et al. 2005) therefore model evaluation was done using average mucuna biomass yield obtained from the two sites. The sowing density was 3.6 plants m^{-2} for maize and 10 m^{-2} for mucuna as observed on the field. Mucuna and maize were used to evaluate the model as a prerequisite for later application of the APSIM model in scenario analysis, which involved assessing potential maize production and soil N and OC dynamics in maize-mucuna rotations.

4.2.5 Model efficiency and data analysis

The predictive performance of the model for maize grain and stover and mucuna total aboveground biomass yield and nutrient contents were evaluated using the root mean square error (RMSE) representing the overall prediction error of the model (Heng et al. 2009). The RMSE measures the deviation between observed and simulated values. It uses the same units of the variable being simulated, and the closer the value is to zero, the better the model simulation performance (Heng et al. 2009). The root mean square error is calculated as:

$$RMSE = \sqrt{1/(N)\sum_{i=1}^{N}(Oi - Si)^2} \quad (4.1)$$

where Si and Oi are simulated and observed values, and N is the number of observations.

The coefficient of efficiency expresses how much the overall deviation between observed and simulated values differs from the overall deviation between observed values (Oi) and their mean value (Ō) (Heng et al. 2009). The model efficiency that measures the robustness of the model has values that range from -∞ to 1, with better model simulation efficiency when values are closer to +1 (Heng et al. 2009). The model efficiency (E) is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{N}(Oi - Si)^2}{\sum_{i=1}^{N}(Oi - \bar{O})^2} \quad (4.2)$$

where Si and Oi are simulated and observed values, N is the number of observations, and Ōi is the mean value of Oi.

The experimental data were analysed using the ANOVA procedure in SPSS version 17.0. On-station data from the two sites were analysed separately. On-farm data were analysed based on farmer wealth category with each farmer treated as a replicate within the respective wealth categories.

4.3 Results

4.3.1 On-station crop yield and nutrient contents

Rainfall during the 2008-2009 cropping season measured at the two on-station study sites was 561 mm, which is slightly above the long-term average annual rainfall of 534 mm. Maize grain and stover yields were highest under the RC treatment as compared to the MD and FP treatments on the two sites. There were no significant differences ($P<0.05$) between fertilizer effects on maize grain and stover yield on the clay soil (Figure 4.1). Although there were no significant differences on the clay soil site a linear response to fertilizer application rates was observed. On the sandy soil the RC treatment also exhibited highest maize grain and stover yields as compared to the other two treatments l. The MD had 41% and 20% higher grain yields, while the RC had 93% and 48% higher grain yields than the FP treatment on the sandy and clay soil respectively. Fertilizer effects were stronger on the sandy soil than on the clay soil. Generally, yields were highest under the RC treatment and lowest under the FP treatment on all soil types. Both grain and stover yields were higher on the clay soil than on the sandy soil.

There was a significant ($p<0.05$) linear response to nitrogen application on the clay soil for both sorghum grain and stover yield (Figure 4.2). Compared to the FP treatment, the MD and RC treatments increased grain yield by about 53% and 72%, respectively. Stover yield also increased linearly in response to increase in N rate where stover yield was 23% and 44% higher than the yield obtained under the FP treatment. On the sandy soil, both sorghum grain and stover showed no response to nitrogen application.

There were no significant differences in the mucuna and lablab yield of total above ground biomass harvested at flowering from the sandy and clay soil sites under three P treatments namely FP, MD and RC (Figure 4.3). There were no significant differences between treatments on all soil types. Average total above ground biomass yield for lablab and mucuna on the sandy soil were 3754 and 3976 kg ha^{-1}, respectively, while on the clay soil average biomass yield for lablab and mucuna was 6067 and 5794 kg ha^{-1}, respectively. Yields were higher on the clay than on the sandy soil.

Total N and phosphorus P contents in maize and sorghum stover at harvesting and mucuna and lablab above ground biomass at flowering were determined (Table 4.2). Nutrients in the maize and sorghum stover showed only slight effects of nitrogen application on the sandy and clay soils, and there were no significant differences across the treatments. Both N and P content in the stover were higher in plants from the clay soil as compared to those from the sandy soil. There were no significant differences between N and P content in mucuna and lablab biomass. Average N content in mucuna biomass was 2.6 % and 2.5%, while total P was 0.37% and 0.35% for the clay and the sandy soil, respectively. Nutrients in lablab biomass were almost similar to those in mucuna biomass.

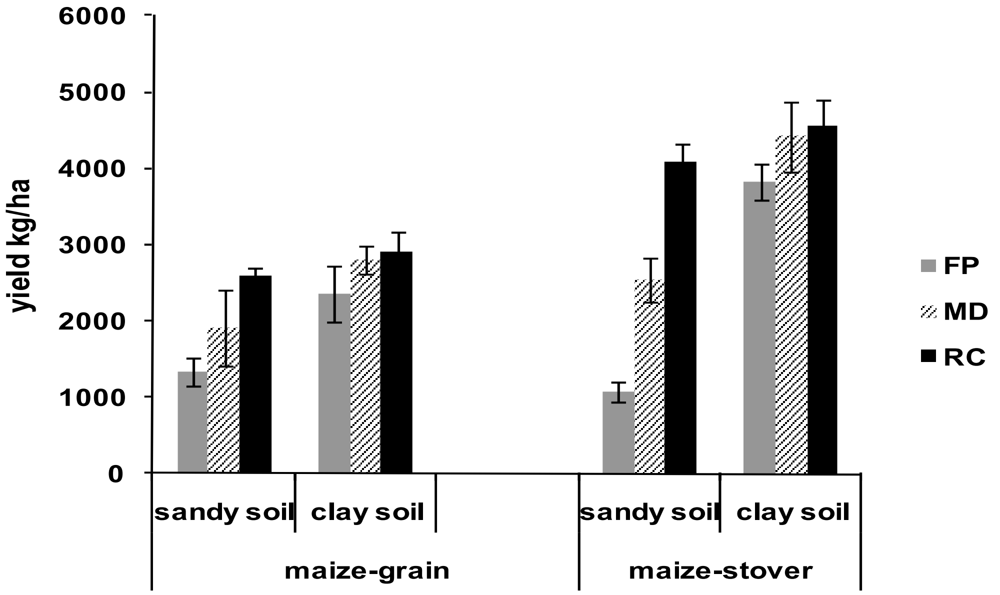

Figure 4.1 Effects of three fertility treatments on maize grain and stover yield on two soil types (sandy and clay). FP = Farmer practice; MD = microdose; RC = recommended rate of nitrogen application.

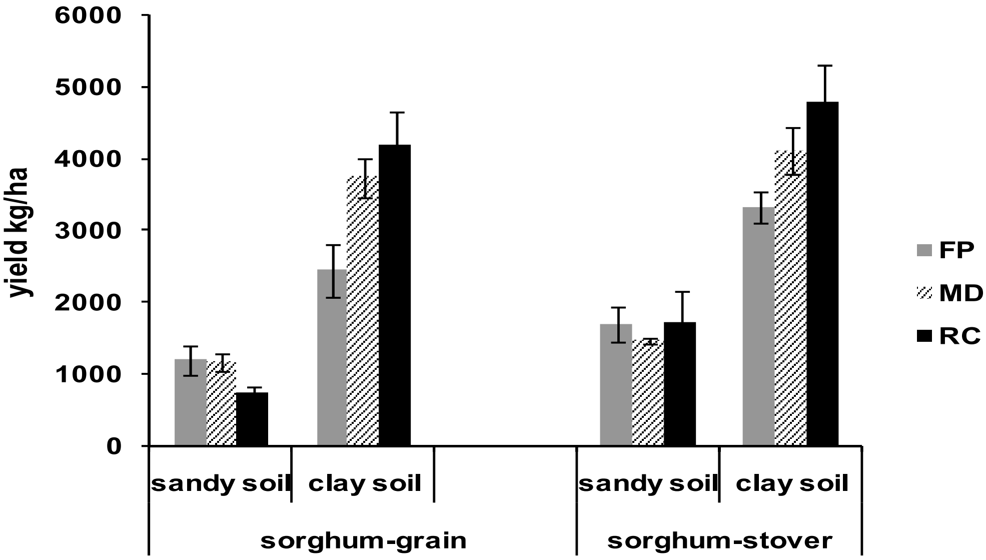

Figure 4.2 Effects of three fertility treatments on sorghum grain and stover yield on two soil types (sandy and clay). FP = Farmer practice; MD = microdose; RC = recommended rate of nitrogen application.

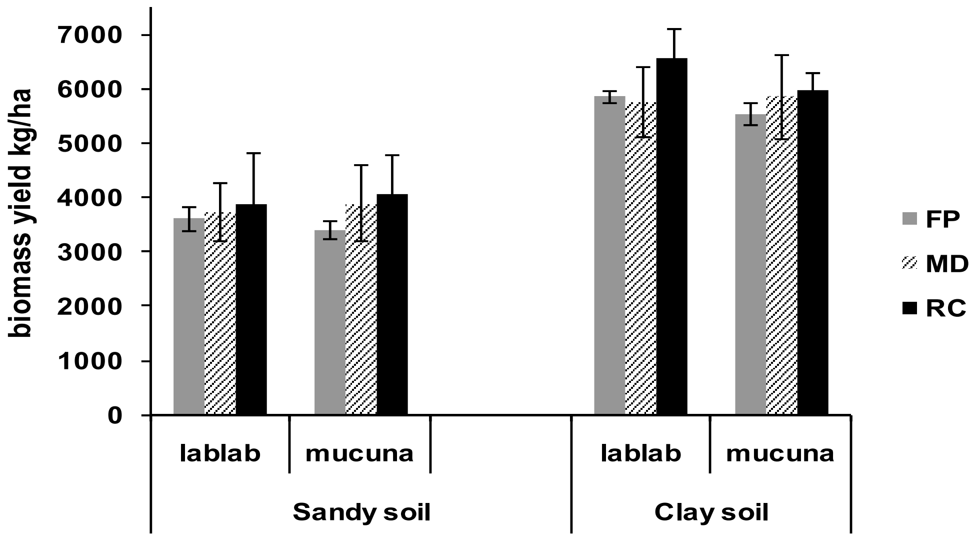

Figure 4.3 Effects of three fertilizer treatments on mucuna and lablab above ground biomass harvested at flowering from two soil types under FP = Farmer practice; MD = microdose; RC = recommended rate of phosphorus application.

Table 4.3 Effects of three fertility treatments on N and P contents in maize and sorghum stover (harvested at maturity) and mucuna and lablab biomass (harvested at flowering) from two soil types (sandy and clay). FP = Farmer practice; MD = microdose; RC = recommended rate of application.

Treatment	**Crop**			
	Maize (stover)	**Sorghum (stover)**	**Mucuna (biomass)**	**Lablab (biomass)**
		Clay soil		
		%N		
	0.47	1.02	2.45	2.72
MD	0.52	1.03	2.62	2.58
RC	0.79	1.04	2.81	2.51
		%P		
FP	0.12	0.10	0.41	0.39
MD	0.10	0.09	0.38	0.44
RC	0.20	0.12	0.37	0.38
		Sandy soil		
		%N		
FP	0.46	1.10	2.33	2.64
MD	0.60	1.12	2.49	2.27
RC	0.68	1.15	2.67	2.39
		%P		
FP	0.11	0.17	0.38	0.37
MD	0.24	0.18	0.36	0.36
RC	0.24	0.20	0.35	0.38

4.3.2 On-farm crop yield and nutrient content

Average rainfall received across the 36 on-farm sites during the 2008-2009 cropping season in Nkayi district was 763 mm, which was 20% higher than the long-term average from 1970 to 2002. Initial soil fertility status across the three farmer wealth categories (poor, average and better-off) was significantly different (Table 4.4), and the better-off farmers had better soils as compared to the other two categories. Effects of soil fertility on maize grain and stover yields were observed, although the differences were not significant (Figure 4.4). Nevertheless, depending on the initial soil fertility status, the responses showed a positive linear trend, i.e., the better the soil the higher the yield. Both grain and stover yields were higher for the better-off farmers as compared to the average and poor farmers. Addition of 17 kg N ha^{-1} (MD treatment) had a slightly significant ($p<0.06$) effect on grain and stover yield across all wealth categories. There was also high yield variability within treatments and wealth categories. The MD treatment led to grain yields that were 45%, 39% and 38% higher than that of the FP treatment for the poor, average and better-off farmers, respectively.

There were no significant differences in sorghum grain and stover yields under the FP and MD treatments across all farmer wealth categories (Figure 4.5). Farmers reported difficulties with sorghum establishment especially on sandy soils. Grain was also badly damaged by birds in all 36 experimental sites. There were significant differences ($p<0.05$) between mean sorghum stover yields across treatments and farmer wealth categories. The highest yields were recorded for the better-off farmers on the MD treatment.

Both wealth and treatment had no significant effect on total aboveground biomass yield of lablab and mucuna harvested at flowering across three wealth categories and two treatments (Figure 4.6). Average lablab biomass yield under FP and MD was 3142 and 2929 kg ha^{-1}, respectively, while mucuna biomass yield under FP and MD treatments was 3505 and 3453 kg ha^{-1}, respectively.

Maize and sorghum stover collected at harvesting and mucuna and lablab above ground biomass collected at flowering from on-farm experiments were analyzed for total N and P (Table 4.5). Both wealth category and treatment had no significant effect on total N and P in maize and sorghum stover and mucuna and lablab biomass. Average N content in lablab and mucuna biomass was 1.9% and 2.0% under the FP treatment while total N content under the MD treatment was 2.0% and 2.0%, respectively.

Table 4.4 Soil fertility status of case study farms at the beginning of the cropping season 2008-2009 in Nkayi district. OC = organic carbon; Total P = total phosphorus; Total N = total nitrogen.

Wealth category	n	OC (%)	Total P (%)	Available P (kg ha^{-1})	Total N (%)	Available N (kg ha^{-1})
Better-off	*12*	0.40±0.04	0.014±0.02	*0.48±0.07*	0.03±0.00	13.48±1.70
Average	12	0.37±0.03	0.010±0.00	0.30±0.05	0.05±0.01	9.65±1.47
Poor	12	0.34±0.02	0.012±0.00	0.36±0.08	0.03±0.00	5.02±1.45
Weighted mean		0.37±0.02	0.012±0.00	0.38±0.03	0.04±0.00	9.87± 0.96
Minimum		0.02	0.00	0.00	0.00	0.00
Maximum		1.24	0.04	2.36	0.25	49.95

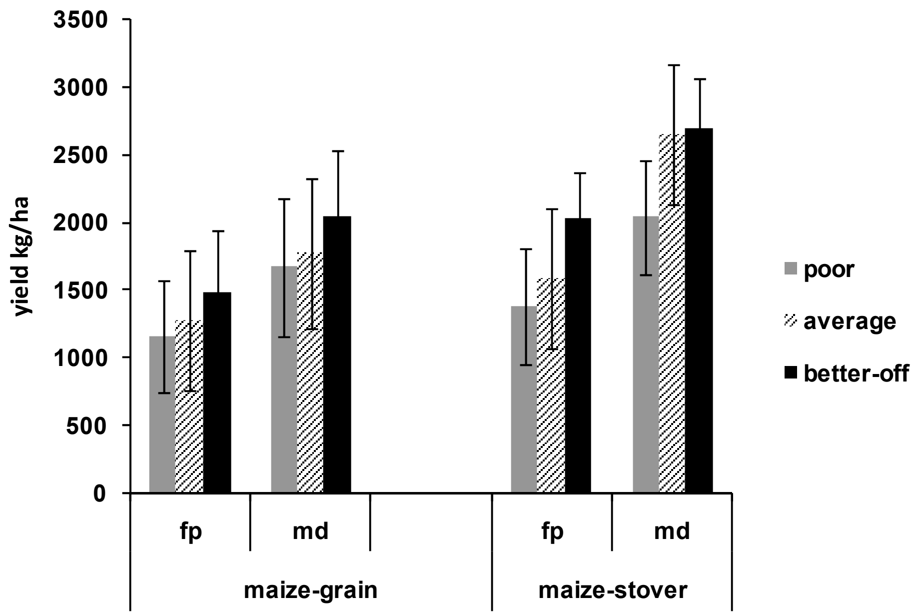

Figure 4.4 Effects of two fertility treatments on maize grain and stover yield harvested from three farmer wealth categories (poor, average and better-off) in Nkayi district. FP = Farmer practice; MD = microdose.

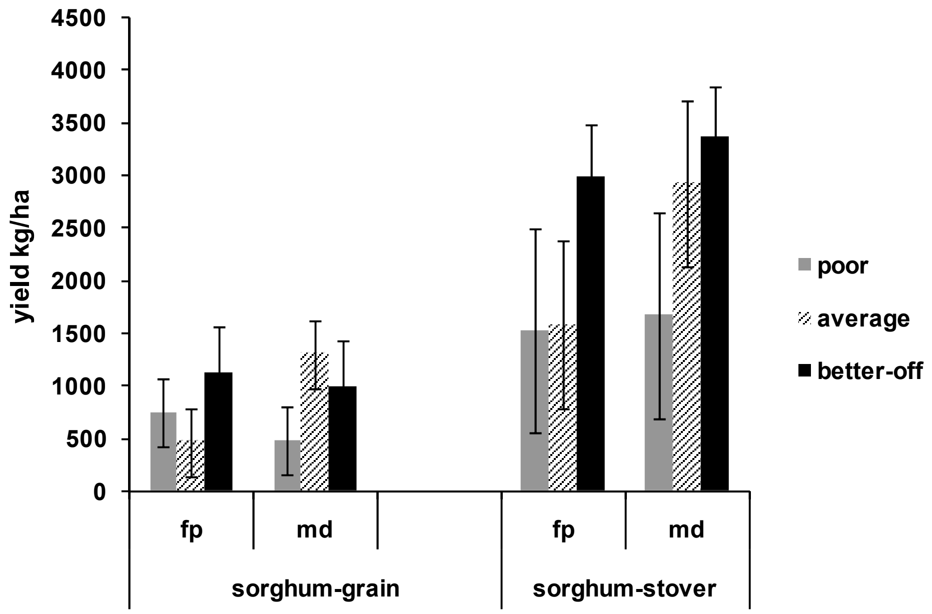

Figure 4.5 Effects of two fertility treatments on sorghum grain and stover yield harvested from three farmer wealth categories (poor, average and better-off) in Nkayi district. FP = Farmer practice; MD = microdose.

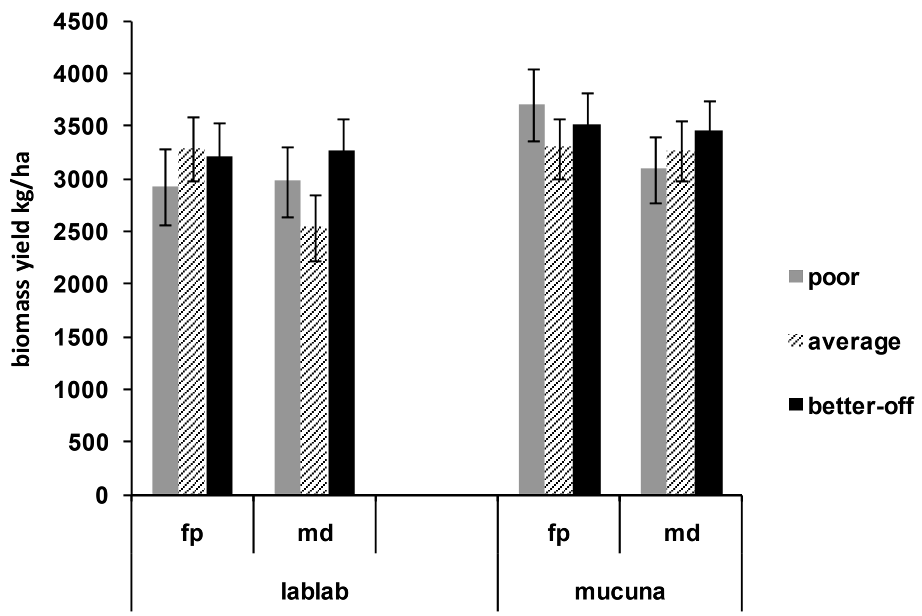

Figure 4.6 Mucuna and lablab above ground biomass harvested at flowering under two P fertilizer treatments in three farmer wealth categories (poor, average and better-off) in Nkayi district. FP = Farmer practice; MD = microdose.

Table 4.5 Nitrogen (N) and phosphorus (P) contents in maize and sorghum stover (harvested at maturity) and mucuna and lablab biomass (harvested at flowering) under different fertilizer treatments across three farmer wealth categories (poor, average and better-off). FP = Farmer practice; MD = microdose.

Treatment	**Crop**			
	Maize (stover)	**Sorghum (stover)**	**Mucuna (biomass)**	**Lablab (biomass)**
		Poor		
		%N		
FP	*0.29*	*0.43*	1.99	1.81
MD	0.51	1.05	1.98	1.67
		%P		
FP	0.08	0.07	0.08	0.11
MD	0.10	0.09	0.09	0.07
		Average		
		%N		
FP	0.48	0.81	1.96	2.03
MD	0.56	0.83	1.93	2.26
		%P		
FP	0.12	0.14	0.12	0.19
MD	0.22	0.12	0.15	0.18
		Better-off		
		%N		
FP	0.44	0.91	1.90	1.79
MD	0.46	1.36	1.94	2.19
		%P		
FP	0.08	0.08	0.10	0.12
MD	**0.08**	**0.10**	**0.13**	**0.14**

4.3.3 Predictive performance of the APSIM model (maize and mucuna yields)

The simulated yields for both maize and mucuna from on-station experiments were higher on the clay soil than on the sandy soil site and agreed reasonably well with measured data from the two sites (Figure 4.7, 4.8 and 4.9). The fertility treatments affected both maize grain and stover yields, which was also well simulated by the model. Maize grain and stover under the RC treatment had the highest yield as compared to the MD and the FP treatments. The model satisfactorily simulated these differences on both soil types. The model also predicted maize grain yield with satisfactory accuracy for the sandy soil. Simulated maize grain yield on the sandy soil was 1.4, 2.2 and 2.3 t ha^{-1} compared to the measured values, which were 1.3, 1.9 and 2.6 t ha^{-1} for the FP, MD and RC treatments, respectively. The model slightly over-predicted maize grain yield under the RC treatment on the clay soil where the measured value was 3.4 t ha^{-1} and the simulated value was 3.9 t ha^{-1}. However, the model simulated stover yield values that were within the experimental error values on the clay soil. Maize stover on the sandy soil under the FP treatment was over-predicted. The measured value was 1.3 t ha^{-1} and the simulated value 2.3 t ha^{-1}. Generally, the model simulated maize grain and stover with satisfactory accuracy; the root mean square error (RMSE) was 0.4 and 0.6 t ha^{-1} for maize grain and stover yield, respectively, across the treatments and sites (Table 4.6). Mucuna biomass yield was also simulated with adequate accuracy with a RMSE of 0.02 t ha^{-1} and coefficient of efficiency (E) 1.0. Average measured mucuna biomass yield was 4.0 t ha^{-1} and the simulated value was 3.8 t ha^{-1} on the sandy soil while measured and simulated values for the clay soil were 5.8 and 5.8 kg t ha^{-1}, respectively.

Nitrogen content in maize stover was affected by N treatments, and tended to be higher under higher N application rates (Figure 4.9). The model predicted the same trend with a RMSE of 0.21 % and E of 1.06 (Table 4.6). The highest N content in maize stover was measured and predicted under the RC treatment, where measured and predicted values for the sandy soil was 0.79 and 0.69 % and for the clay soil was 0.68 and 0.51 %, respectively. Measured nitrogen content in mucuna biomass was 2.60 and 2.63 % for the sandy and clay soil sites and simulated content was 2.88 and 2.73%, respectively. The model simulated nitrogen content in mucuna biomass with satisfactory accuracy with a RMSE of 0.16 % and the coefficient of efficiency of 0.94.

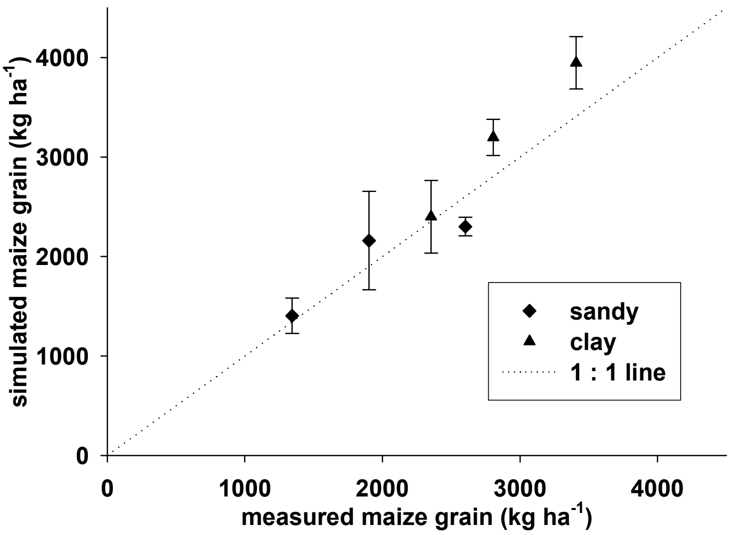

Figure 4.7 Measured and simulated maize grain across two soil types. Error bars denote standard errors of measured means

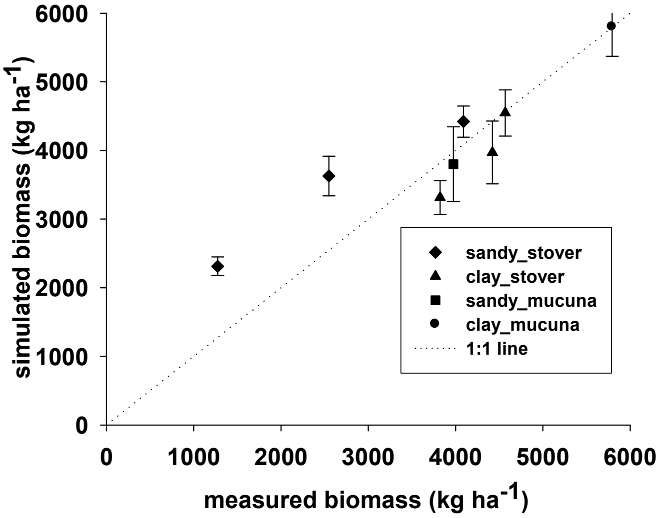

Figure 4.8 Measured and simulated maize stover and mucuna biomass across two soil types and three fertility treatments. Error bars denote standard errors of measured means.

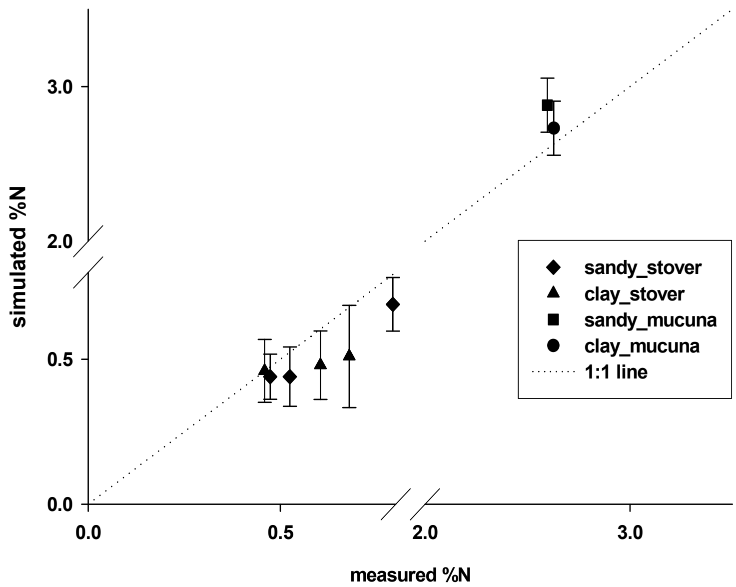

Figure 4.9 Measured and simulated nitrogen content in maize stover and mucuna biomass across the two sites. Error bars denote standard errors of measured means.

Table 4.6 The root mean square error (RMSE) and coefficient of efficiency (E) between measured maize grain, stover and mucuna biomass yield and nitrogen content.

	RMSE	E
	Maize	
Grain (kg ha^{-1})	404	0.99
Stover (kg ha^{-1})	599	0.99
Stover N (%)	210	1.06
	Mucuna	
Biomass (kg ha^{-1})	304	0.99
Biomass N (%)	156	0.94

4.4 Discussion and conclusions

4.4.1 On-farm crop production

The need to understand the potential production of different crops under smallholder farming systems in semi-arid areas is addressed in this study. Maize and sorghum are the main staple grain crops in Zimbabwe, and their on-farm production performance under micro-dose (MD) treatment has been tested across a broad spectrum of soil, farmer management and seasonal climate conditions in smallholder farmer systems (Twomlow et al. 2008). In the current study, the MD treatment increased maize grain yields by about 38-45 % while stover was increased by 33-67% across three farmer wealth categories. In a wide-scale testing of the MD treatment in southern Zimbabwe, Twomlow et al (2008) showed that the MD treatment increased maize grain yield by 30-50% across several locations.

In the current study sorghum grain production was poor due to bird damage. Poor establishment of sorghum on sandy soils was also reported by farmers. A number of factors can adversely affect sorghum stand establishment such as water deficit, extreme soil temperatures, and unfavorable soil physical and chemical properties. The poor establishment of sorghum on sandy soils has been speculated to be caused by poor root development and capability of sorghum to extract P in P-deficient soils (Twomlow et al. 2008). On-farm soil had low available P levels, 0.10, 0.08 and 0.14 ppm for the poor, average and better-off farmers, respectively. Work done by Twomlow et al (2008) was done on homestead fields which are considered to be more fertile and in the current study, poor sorghum stand establishment were also experienced on-station , although the soils were not P-deficient(P > 10 ppm). Further work should be done to establish the potential causes of poor sorghum establishment on sandy soils.

Mucuna and lablab are relatively new in the smallholder farming systems in the semi-arid areas, although a substantial amount of research has been done on smallholder farmers in the sub-humid areas of Zimbabwe. On exhausted sandy soils in six districts in Zimbabwe, mucuna biomass yield ranged from 2-6 t ha^{-1} and up to 10 t ha^{-1} without and with P fertilizer application, respectively (Waddington et al. 2004). The biomass yield of mucuna grown for 19 weeks on sandy soils ranged from 4.5 to 8.5 t ha^{-1} dry matter, on sandy loam soil it was 9.5 t ha^{-1} and on clay soil it was 11.2 t ha^{-1} in sub-humid areas of Zimbabwe (Whitbread et al. 2004). Average lablab and mucuna biomass yield obtained in the current study was 3.0 and 3.5 t ha^{-1} dry matter, respectively. Previous studies on mucuna biomass production on smallholder farmers show that P plays an important role in biomass production. Both mucuna and lablab did not respond to the MD treatment where P application was 11 kg ha^{-1} which was 50% of the recommended rate. Phosphorus content in mucuna and lablab biomass was 0.12 and 0.13%, respectively; these values are below the marginal range at flowering of 0.20-0.23% (Reuter and Robertson 1997). Initial P in the soil was 0.10, 0.08 and 0.14 ppm for the poor, average and better-off farmers, respectively. Low P in plant biomass could be attributed to P deficiency in the soils, hence the possibility of no fertilizer response. In Indonesia Hairiah et al (1995) found no responses of mucuna to P applications on soils with low P content (cited in Shoko 2009).

Soil P also affects N accumulation in legume biomass (Lekberg and Koide 200). Nitrogen content of mucuna and lablab collected from on-farm experiments was 31% less than that observed on-station. Although the values are lower they are within the range of measured values (1.76-3.68%) under smallholder farming systems and for on-station experiments for biomass harvested at different stages (Nyambati 2002; Maasdorp et al. 2004; Cook et al. 2005). Results from this study show that mucuna and lablab have the potential to provide 3 t ha^{-1} yr^{-1} which, can be used as mulch to improve crop production or as fodder to improve livestock productivity. Although mucuna and lablab produced almost similar amounts of biomass under smallholder farmer conditions, most farmers preferred mucuna to lablab. Lablab was affected by aphids, and seed production was not good, while mucuna was not affected by any pests and seed production was good. Mucuna is known to have insecticidal effects and can suppress weeds such as *Imperata cylindrical* and *Striga,* which are some of the most problematic weeds in depleted sandy soils in most smallholder farming systems (Weber 1996; Jasi et al. 2003; Ikie et al. 2006).

Nitrogen in maize and sorghum stover and mucuna biomass was evaluated mainly for the potential use of these crops as an adjunct to livestock dry season feed. In the smallholder crop-livestock farming systems of the semi-arid tropics, natural pasture provides the basic feed for ruminant animal production (Undi et al. 2000; Woyengo et al. 2004; Hall et al. 2007*).* Grass biomass and quality is low during the dry season with protein content dropping from 120-160 g crude protein CP kg^{-1} dry matter (DM) in the growing season to as low as 10-20 CP kg^{-1} DM in the dry season (Baloyi et al. 1997; Maasdorp and Titterton 1997; Mpairwe, 2005). Maize and sorghum stover produced under the FP treatment contained about 25 and 45 CP g kg^{-1}, respectively, while that from the MD treatment contained about 32 and 68 CP g kg^{-1}, respectively. Crude protein content in mucuna and lablab was 122 and 123 CP g kg^{-1}, respectively. A combination of energy-providing crops such as maize and sorghum stover and protein rich crop such as herbaceous legumes can be used to produce protein-rich silage, adequate for livestock maintenance and production (Maasdorp and Titterton 1997).

4.4.2 Predictive performance of APSIM

Simulation models assist in evaluating promising options for changes in livestock, crop, soil and water management in different production systems (Cavero et al. 2000; Yang et al. 2006). The predictive performance of APSIM for maize grain and stover yield and stover N content was tested under three fertility treatments on two soil types. Maize yield on the sandy soil site was lower than that on the clay soil site. This could be attributed to late sowing dates and differences in initial soil fertility conditions. Crops on the clay soil site were planted on 29 November, while those on the sandy soil site were planted on 12 December 2008. The model simulated these management practice differences satisfactorily. The model also managed to simulate maize response to different fertilizer application rates as observed from field data under the FP, MD and RC treatments. Simulated N content in the maize stover and mucuna biomass was also within experimental error values. Mucuna biomass was well simulated, with simulated yields within the experimental error on the two sites. Mucuna did not respond to the different P application rates, which were 11 and 22 kg ha^{-1} for the MD and RC treatment, respectively. This could be attributed to initial P in the soils which was > 10 ppm. This is considered optimal for both mucuna and maize production (Robertson et al. 2005). Optimum soil P levels were also confirmed by amount of P in mucuna and lablab biomass, which was within the adequate range of 0.25-0.40% at flowering stage (Reuter and Robertson 1997). Percent P in mucuna biomass at flowering on the sandy soil was 0.38, 0.36 and 0.35% while on the clay soil it was 0.41, 0.38 and 0.37% under the FP, MD and RC treatments, respectively. However, Shoko et al (2009) reported mucuna P responses in Zimbabwe, at a rate of 40 kg P ha^{-1} on a sandy loam soil which had initial P content of 15 ppm.

In the current study, maize stover and mucuna biomass production were evaluated mainly for their prospective contribution to dry-season livestock feed and soil fertility in smallholder farming systems. Therefore, their nitrogen content was also evaluated. Measured and simulated N content in both maize stover and mucuna biomass were well simulated by the model. Most simulated values were within experimental error values. Average N content in mucuna was comparable with those for APSIM-Mucuna simulation results reported in evaluations (Keating et al. 1992; Robertson et al. 2004) and those measured in field experiments (Nyambati 2002; Maasdorp et al. 2004; Cook et al. 2005).

The model shows that it can simulate maize and mucuna production in the semi-arid areas, and hence can serve as an important decision-making tool in crop management and production that can be used to explore promising options for changes in crop, soil, and water management in production fields (Yang et al. 2006). The suitability of APSIM in simulating crop production in smallholder farming systems in the semi-arid tropics in Africa has been tested over several years and in a number of regions (Dimes et al. 2003; Whitbread et al. 2010). There is paucity of information on the potential of mucuna to improve soil fertility, crop production and as livestock feed in smallholder mixed crop-livestock systems in the semi-arid areas of Zimbabwe. The APSIM model can be used to further explore these effects under varying climatic and management conditions. The model can be used to address questions such as: How much biomass can be used as mulch and fodder and to what extent can the quantities affect crop production, soil chemical properties and livestock production?

5 MAIZE-MUCUNA ROTATION: AN ALTERNATIVE TECHNOLOGY TO IMPROVE WATER PRODUCTIVITY IN SMALLHOLDER FARMING SYSTEMS.

5.1 Introduction

Crop water productivity (WP) is generally defined as the ratio of crop yield to actual evapotranspiration (Cai and Rosegrant 2003; Liu et al. 2008), and can be improved by producing the same output with less water or by increasing output for the same amount of water (Mustafa et al. 2008). Water productivity of cereal crops in sub-Saharan Africa currently ranges from 0.04 to 0.1 kg m^{-3}, while the potential is more than 1.0 kg m^{-3} (Rockström et al. 2003). Similarly, rain-fed crop production systems in the semi-arid tropics of Zimbabwe are also characterized by low water productivity despite research and extension efforts to develop and popularize improved genetic material and management practices (Ahmed et al.1997). Low WP is partly attributed to inherent low soil fertility, which is further exacerbated by continuous cropping without addition of adequate organic and inorganic fertilizers due to unavailability and high costs (Nzuma et al. 1998; Mugwe et al. 2004). The challenge is to improve soil fertility and water management in order to increase the productive green water use under rain-fed cropping systems (Rockström et al. 2003). Sandy soils are predominant in the smallholder farming systems of Zimbabwe, and these soils are inherently infertile, poorly buffered and contain small amounts of soil organic matter (SOM) (Zingore 2006). Low SOM is also attributed to high turnover rates caused by the high tropical temperatures and the poor protection offered by sandy soils to microbial attack (Mapfumo and Giller 2001). Therefore there is a need to occasionally apply external organic inputs, which will alleviate adverse effects on crop productivity.

Alternative sources of soil amendments need to be sought in several areas in Africa, where soil fertility needs to be rebuilt and where high cost and low supply quantities limit inorganic fertilizer application (Omotayo and Chukwuka 2009). In Zimbabwe, leguminous forage crops such as *Lablab purpureus, Mucuna pruriens, Medicago sativa*, and *Cajanus cajan* have been introduced to commercial and communal farmers mostly in the sub-humid areas, where productivity was improved through provision of alternative low-cost fertilizers for crop production (Maasdorp and

Titterton 1997; Ngongoni et al. 2007). Grain legumes are also known to improve soil fertility, but farmers only grow them on small areas because of their preference for cereal staples, lack of high quality seeds, disease constraints and lack of output markets (Ncube et al, 2008). In contrast, forage legumes, such as mucuna, can be grown on fallow land, seed can be reproduced, and biomass can be used to improve soil fertility or livestock feed. Mucuna production has been successfully tested under smallholder conditions on exhausted sandy soils where biomass yield ranged from 2 to 6 t ha^{-1} and up to 10 t ha^{-1} without and with P fertilizer application, respectively (Waddington et al. 2004). Maize grain increases of more than 64% have been measured in Zimbabwe after application of mucuna as green manure, where nitrogen (N) contribution from mucuna biomass ranged from 101 to 348 kg N ha^{-1} (Whitbread et al. 2004). In Malawi, maize following mucuna yielded about 1.5 t ha^{-1}, while maize under the recommended fertilizer application yielded 2.3 t ha^{-1} and from unfertilized plots 0.8 t ha^{-1} (Sakala et al. 2003). Mucuna is a vigorous twining crop that can grow on sandy soils with low available phosphorus (P) (Cook et al. 2005), and can suppress weeds such as *Imperata cylindrical* and *Striga*, which are some of the most problematic weeds in depleted sandy soils in most smallholder farming systems (Weber 1996; Jasi et al. 2003; Ikie et al. 2006). Mucuna can be used as forage, silage, and hay, and can produce high yields depending on rainfall even in soils with low available P (Cook et al. 2005), which makes it an appropriate crop for mixed crop-livestock smallholder farming systems.

Maize-mucuna rotations can be used as an alternative technology to improve soil fertility, and crop and livestock productivity. The challenge is how to achieve a clear understanding of the potential productivity of such cropping systems, and to what extent these can satisfy both crop (soil improvement) and livestock (feed) needs. To quantify biomass production and water productivity of different cropping systems and their long-term impacts on soil fertility experimentally is extremely cost and time consuming. A preferred approach is to use well-proven crop simulation models, hence a modelling approach was taken in this study. The model used was the Agriculture Production Systems sIMulator (APSIM). APSIM is a modular modeling framework that can be used to simulate complex climate-soil-vegetation management systems (McCown et al. 1996; Keating et al. 2003). It has been tested in Africa to evaluate crop production under a wide range of management systems and conditions. In the Sahel zone for example, Akponikpe et al. (2010) investigated millet response to N with a view to establish recommendations for N application better adapted to smallholder farmers. Delve et al. (2009) evaluated P response in annual crops in eastern and western Kenya. Ncube et al. (2008) assessed the impact of grain legumes on cereal crops grown in rotation in nutrient-deficient systems in Zimbabwe. Shamudzarira, (2002) evaluated the potential of mucuna green manure technologies to improve soil fertility and crop production in southern Africa, while Robertson et al. (2004) evaluated the response of maize to previous mucuna and N application in Malawi.

Published research work on maize-mucuna rotations in Zimbabwe is mostly on a short-term basis, and these cropping systems have mainly been tested for crop improvement especially in cereal grain production. Long-term effects of maize-mucuna rotations on soil fertility and potential production for food and feed have not been tested under smallholder farming systems in the semi-arid areas of Zimbabwe. The APSIM model was used in this study to evaluate the long-term effects of maize-mucuna rotations on (i) biomass production, grain yield, and water productivity of maize and mucuna, (ii) dynamics of soil organic carbon and total nitrogen, and (iii) to investigate the degree of water and nitrogen stress in maize-mucuna rotation systems across seasons under three farmer wealth categories.

5.2 Materials and method

5.2.1 APSIM model description and parameterization

After evaluating the APSIM model regarding its predictive performance for maize grain and stover and mucuna biomass yield (Chapter 4), the model was used to evaluate the long-term effects of different crop production systems on water productivity (WP), total soil nitrogen (TN) and soil organic carbon (SOC). The model was tested using specific household information that was collected from the farmers during the study period (2008-2009) in Nkayi District. The district was selected on the basis that it has higher livestock numbers as compared to other districts in the same natural region (Chapter 2), and that there is good potential for livestock production (Homann et al. 2007).

Predominant soils in the area are Kalahari sands, which are low in N, P, and S and cation exchange capacity owing to low clay and organic matter contents (Grant 1967a; 1967b; 1970; Nyamapfene 1981 cited in FAO 2006).

To simulate the cases in this study, the APSIM-maize, APSIM-mucuna (Robertson et al. 2004), SOILN2 and SOILWAT2 modules (Probert et al. 1998) were linked within the APSIM version 6.1. The crop modules (APSIM-maize and APSIM-mucuna) simulate on a daily time-step the phenological development, leaf area development, biomass accumulation (above and below ground), and grain yield, N fixation by legumes, and water and N uptake. Crop growth is also determined by climatic conditions (temperature, rainfall, radiation) where potential biomass growth is a function of the intercepted radiation and radiation use efficiency.

The crop modules have 11 crop stages and 10 phases (time between stages). Commencement of each stage is determined by accumulation of thermal time except during the sowing to germination period, which is driven by soil moisture. Between the stage of emergence and flowering, the calculated daily thermal time is reduced when water or N stress occurs, resulting in delayed phenology. Both the maize and mucuna modules require specific parameters related to crop phenology. The cultivars used in the experiments have set parameters in APSIM. The maize cultivar SC401 is an early maturing hybrid from Zimbabwe and has been extensively used by a number of researchers to simulate maize production in Africa (Probert 2007; Delve et al 2009). The mucuna_gen in APSIM developed by Robetson et al. (2004) is a typical cultivar, which is grown under smallholder conditions in southern Africa. Testing of mucuna in APSIM has only been done in Africa, hence Robertson et al. (2004) states that APSIM-Mucuna can be used with high confidence in this part of Africa.

The SOILWAT2 module uses a multi-layer, cascading approach for the water balance. Soil water characteristics are described in terms of volumetric water content at saturation (SAT), drained upper limit (DUL), and lower limit (LL15) of plant extractable soil water. Estimates of SAT, DUL and LL15 were obtained for each experimental site from soil water profiles measured during the 2002-2004 cropping season (Masikati 2006; Ncube et al. 2008) for the sandy soil site and during the 2004-2006 cropping season (Mupangwa 2009) for the clay soil site. In the SOILWAT2 module, run-off is estimated using the United States Department of Agriculture run-off curve number (Probert 2007). The partitioning of rainfall between infiltration and runoff is determined primarily by the curve number (cn2-bare). The cn2_bare parameter (0-100) is an input to the model and describes the runoff propensity of the soil under bare soil conditions for the given rainfall environment and land configurations, i.e, the higher the number, the higher the simulated runoff. The soil curve number (cn2-bare) was set to 85 similar to that used by Probert (2007). The soil evaporation is determined by the first stage (U) and second stage (CONA) evaporation. The evaporation and CONA parameters (Ritchie 1972) were held constant at 6 mm and 3.5 mm day-$^{0.5}$, respectively, i.e., they were adjusted to closely relate to the values used by Ncube (2008) for soils at the same study site and by Probert (2007) on a sandy soil in the same tropical environment. The plant available water capacity (PAWC) was 59 mm (0-100 cm depth).

The SOILN2 module has three soil organic matter pools (FOM, BIOM and HUM) with transformations considered in each soil layer. The FOM is the fresh organic matter pool, which is partitioned into the BIOM and HUM pools. The BIOM consists of the more labile, soil microbial products, and the HUM the remaining soil organic matter. The flows between the different pools are calculated in terms of carbon (C); the corresponding N flows depend on the C:N ratio of the receiving pool. The C:N ratios of the these pools are assumed to be constant through time; the C:N for BIOM is specified in the INI file, whilst the C:N of HUM is derived from the C:N ratio of the soil that is the input. The starting conditions of simulations were also defined for percent organic carbon (OC) and nitrate-nitrogen (NO_3-N) measured from on-farm experimental sites at the beginning of the cropping season 2008-2009 (Table 5.1).

The surface organic matter (SURFACEOM) module in APSIM includes crop residues and manure. Manure and crop residues on the soil surface can be removed or incorporated into the soil during a tillage event or decompose on the surface. Manure and crop residues are defined in terms of mass, carbon content, inorganic and organic nitrogen and phosphorus. An overall effective cover value (0-1) is calculated using all surface organic matter components present, for the purpose of subsequently calculating the surface material effect on soil evaporation and runoff. During a tillage event, surfaceOM N and C is incorporated into the soil to the nominated tillage depth, and added to the respective soil mineral N and fresh organic matter pools. Decomposition of crop residues or manure is calculated using a simple exponential decay algorithm (Probert et al. 1998; Dimes and Revanuru 2004). Decomposition of residues with high C:N ratio creates an immobilization demand, which is satisfied from mineral-N in the uppermost soil layers. The default C:N ratio of maize and mucuna were used while that of manure was set to 23 (Chivenge et al. 2004; Masikati 2006)

Table 5.1 Initial soil organic carbon (OC) and nitrate-nitrogen (NO_3-N) of soil samples collected from smallholder farms in Nkayi district, in December 2008 for three farmer wealth categories.

Layer number	**1**	**2**	**3**	**4**	**5**	**6**
Layer depth (mm)	150	150	150	150	150	250
			Poor			
OC (%)	0.45	0.40	0.30	0.31	0.20	0.20
NO_3-N (ppm)	1.87	1.19	1.63	0.88	0.92	0.92
			Average			
OC (%)	0.56	0.42	0.36	0.31	0.21	0.21
NO_3-N (ppm)	2.86	1.04	2.58	2.58	2.70	0.94
			Better-off			
OC (%)	0.56	0.48	0.40	0.28	0.23	0.23
NO_3-N (ppm)	4.50	4.26	2.69	3.18	4.04	1.35

5.2.2 Climate data and crop management

Simulations were run for 30 years from 1978 to 2008 using daily weather data (precipitation, minimum and maximum temperatures, and radiation) recorded by the national weather bureau of the Matopos Research Station. Sandy soils, which are predominant in the smallholder farming systems of Zimbabwe, were used for the simulations. A short duration maize variety SC401 and mucuna were planted at 3.5 and 10 plants m^{-2}, respectively, and the sowing window was from November to December each year. Soil moisture conditions for sowing were set to 20 mm cumulative rainfall over 5 days. Initial soil conditions (soil NO3-N and OC) were set to match those measured on-farm in Nkayi District (Table 5.1). The research station is located between 20° 25′ south and 28° 24′ east, while Nkayi District lies between 19° 00′ south and 28° 20′ east.. Both sites are characterized by semi-arid climatic conditions with annual rainfall ranging between 450 and 650 mm.

Simulations were done for three farmer wealth categories that were determined based mainly on cattle ownership (Chapter 1). This action was important as initial soil fertility differed across wealth categories. Furthermore the number of cattle determines the amount of residues to be removed for feed. In mixed crop-livestock systems, crop and livestock complement and compete with each other especially for resources such as crop residues. In these systems, farmers opt to use crop residues to feed livestock, and this has been a stumbling block for promoting conservation agriculture (Probert 2007). This study aims to determine the effects of different residue removal rates as determined by livestock feed requirements during the dry season on crop production and potential feed supply. To evaluate the robustness of the different crop production systems, the amounts of residues removed yearly were estimated to be equivalent to the amount required to meet 100% of daily dry matter intake (DMI) requirements during 3 months of critical feed shortages each year. Daily DMI requirements were calculated as 2.5% of liveweight (Table 5.2). The average liveweight of a mature cow measured on-farm was 300 kg. It was also assumed that farmers use 1 ha for maize production each year under the three treatments, and that mucuna was grown on 1 ha of fallow land (Chapter 3).

Table 5.2 Cattle feed requirements

Average livestock holding*	2, 6 and 14 for the poor, average and better-off farmers, respectively.
Average live weight*	300 kg
Approximate daily dry matter intake**	2.5% of live weight
Critical feed shortage period*	September to November (~90 days)

* ICRISAT survey, (2008); **FAO, (2002)

Scenario 1- farmer practice (FP)

This scenario was set up to simulate the conventional farming practices of smallholder farmers in the semi-arid tropics of Zimbabwe. No soil fertility amendments were added. Weeding was carried out twice for the poor and average farmers at 25 and 50 days after sowing (DAS), while for the better-off farmers it was done three times at 20-day intervals. The capacity to weed mainly depends on the availability of draft power. The better-off farmers had more livestock hence better weeding capacity. Crop residues in this scenario were removed at harvest to simulate cut and carry systems, where residues are collected and stored and used as feed during the dry season.

Scenario 2 –manure application (MN)

Livestock manure, especially from cattle, is one of the most available but most under-utilized organic soil amendments on smallholder farms. Availability of manure is determined by the number of animals, while field application depends on labor availability. In this scenario, manure was applied 30 days before the start of the sowing window. This is practiced by farmers, as manure is carried to the fields before the onset of the rainy season. Manure production was estimated using a dry weight production of 3.3 kg of dung day^{-1} TLU^{-1} for cattle (Haileslassie et al. 2009), and the application rate was determined by the total size of cropland owned by farmers in the different wealth categories (Chapter 2). This resulted in application rates of 411, 1906 and 4448 kg ha^{-1} for the poor, average and better-off farmers, respectively. Weeding was done as for the FP scenario.

Scenario – 3 maize-mucuna rotation and manure (MMR)

In this scenario, maize was grown in rotation with mucuna. Land holding in Nkayi is on average 3.9 ha per household (Chapter 3). This allows farmers to have a crop of maize and mucuna each year. To evaluate the full benefits of this technology on crop production and soil fertility, the rotation was combined with manure using the same application rates as for the MN scenario. Harvested crop residues were removed at differing rates depending on livestock numbers owned by the different farmer groups. Crop residues were assumed to be used for dry season feed to meet 100% animal dry matter requirements for 3 months of critical feed shortages (Chapter 2). Weeding was done as for the FP and MN scenarios.

5.2.3 Estimating crop water productivity

To quantify evapotranspiration (ET), the APSIM model uses the SOILWAT2 module. This module uses a multi-layer, cascading approach for the water balance with run-off estimated using the United States Department of Agriculture (USDA) run-off curve number (Probert 2007). The partitioning of rainfall between infiltration and runoff is determined primarily by the soil curve number (cn2-bare). The model also simulates the effects of surface residues and crop cover on modifying runoff and reducing potential soil evaporation. Soil evaporation is determined by the first stage (U) and second stage (CONA) evaporation. Evapotranspiration was calculated as:

$$ET = incrop\ precipitation - (runoff + drainage) \tag{5.1}$$

Water productivity for mucuna biomass was calculated by dividing above-ground dry matter (kg ha^{-1}) by ET. A similar approach was used to calculate maize grain water productivity (WP_{grain}) calculated as grain yield divided by ET.

5.2.4 Soil organic carbon and total nitrogen

The change in SOC and TN under the different treatments was calculated as the rate of change in these variables per year (kg ha^{-1} $year^{-1}$) as:

$$Change\ in\ TN = \frac{TN_{final} - TN_{initial}}{Number\ of\ simulated\ years} \tag{5.2}$$

$$Change\ in\ SOC = \frac{SOC_{final} - SOC_{initial}}{Number\ of\ simulated\ years} \tag{5.3}$$

where TN_{final} and SOC_{final} are TN and SOC at the end of the 30-year simulation period, and $TN_{initial}$ and SOC_{intial} are TN and SOC at the beginning of the simulation period.

For analysis, the top 30 cm of the soil profile was used to evaluate the effects of the different treatments on SOC across the three wealth categories. The top 30 cm were selected as user-defined tillage depth in the model was 180 mm, which simulates the on-farm plough layer depth (Masikati 2006). Total N in the whole soil profile (0-70 cm) was considered for analysis as N is a mobile nutrient.

5.3 Results

5.3.1 Maize grain and stover and mucuna biomass yield

The simulations show inter-annual grain yield variability across all treatments. The highest variability was in the MMR treatment (Figure 5.1). In the FP treatment inter-annual variability of grain yield ranged from 0.3, 0.4 and 0.4 t ha^{-1} to 2.2, 2.5 and 2.6 t ha^{-1} for the poor, average and better-off farmer categories, respectively. Maize grain yield under the MN treatment ranged from 0.3, 0.4 and 0.4 t ha^{-1} to 2.3, 3.0 and 3.6 t ha^{-1}. The MMR treatment increased inter-annual grain yield variability across all farmer wealth categories as compared to the FP and MN treatments. In the MMR treatment, grain yield ranged from 0.1, 0.2 and 0.2 t ha^{-1} to 4.5, 4.9 and 4.9 t ha^{-1} for the poor, average and better-off framers, respectively. Here, grain yield variability was higher within the 25 and 75 percentile for the poor and average farmers as compared to the better-off farmers.

Although there were differences in the highest simulated grain yields, the lowest grain yields were all similar and below 0.5 t ha^{-1} across all treatments and wealth categories. The highest grain yields under the MMR treatment were more than double those for the FP and MN treatments for the poor and average farmer categories. For the better-off farmers, the highest grain yield in the MN treatment was 2.7 while that of the MMR treatment was 4.7 t ha^{-1}. In 75% of the simulated years, grain yield in the MMR treatment was more than 1 t ha^{-1} across all wealth categories, while that in the FP treatment was below 0.4, 0.5 and 0.6 t ha^{-1} for the poor, average and better-off farmer categories, respectively. Generally, the MMR treatment increased grain yields substantially across all wealth categories as compared to the FP and MN treatments.

Maize stover yields across the three treatments and farmer wealth categories also showed inter-annual variability over the simulation period. Stover yield variability showed a similar pattern to that of maize grain yield where highest variability was in the MMR treatment. However, the lowest yields were not similar across treatments. Lowest stover yields were 0.5, 0.7 and 0.7 t ha^{-1} in the FP treatment, while in the MN treatment yield was 0.5, 0.8 and 1.1 t ha^{-1} for the poor, average and better-off farmer categories, respectively. In the MMR treatment, the lowest stover yield was 1.5, 1.5 and 1.6 t ha^{-1} for the poor, average and better-off farmer categories, respectively. The highest stover yields in the FP treatment were 4.0, 4.5 and 4.7 t ha^{-1}, while those in the MN treatment were, 4.2 and 5.2 and 5.9 t ha^{-1} for the poor, average and better-off farmer categories, respectively. In the MMR treatment, highest stover yields were 7.5, 8.1 and 6.8 t ha^{-1} for the poor, average and better-off farmer categories, respectively. Inter-annual variability of stover yield in the MMR treatment within the 25 and 75 percentiles was lower for the better-off farmers as compared to the poor and average farmers. Generally, the MMR treatment substantially increased stover yields across all wealth categories. In 75% of the simulated years, stover yield under the MMR treatment was more than 3 t ha^{-1}, while that under the FP treatment was below 1 t ha^{-1} across all wealth categories.

There was inter-annual variability in the mucuna biomass yield across all farmer wealth categories (Figure 5.3), and lowest biomass yield was 0.5 t ha^{-1} and highest was 7.1 t ha^{-1} across all wealth categories.

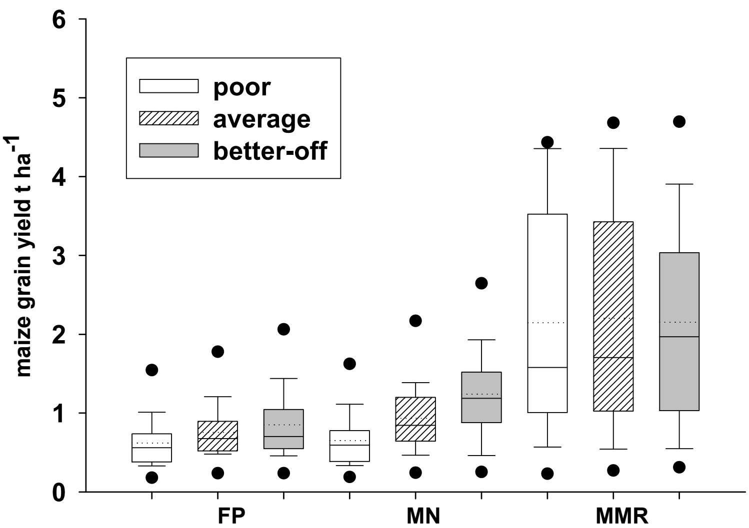

Figure 5.1 Simulated effects of soil fertility management on maize grain yield under three farmer wealth categories poor, average and better-off. The box-and-whisker diagrams include: (dotted and solid lines) mean and the median values respectively; (cross bars) maximum and minimum values; (circles) extreme values. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation

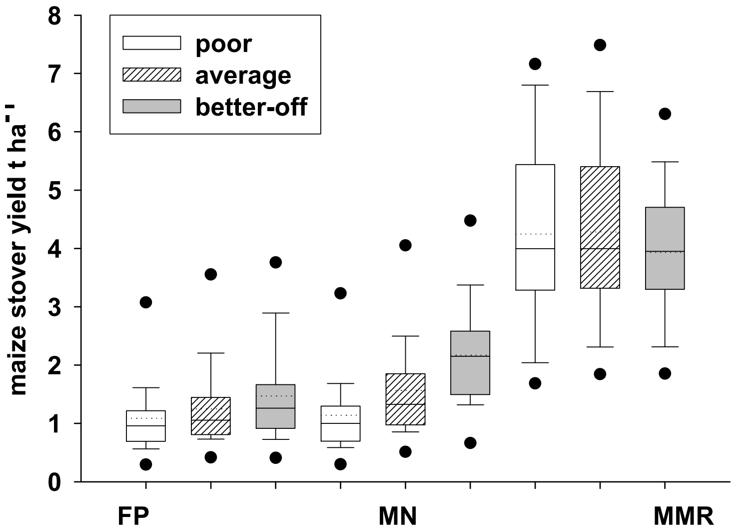

Figure 5.2 Simulated effects of soil fertility management on maize stover yield under three farmer wealth categories poor, average and better-off. Legends are the same as for figure 5.1. FP = farmer practice, MN = Manure, MMR = maize-mucuna rotation

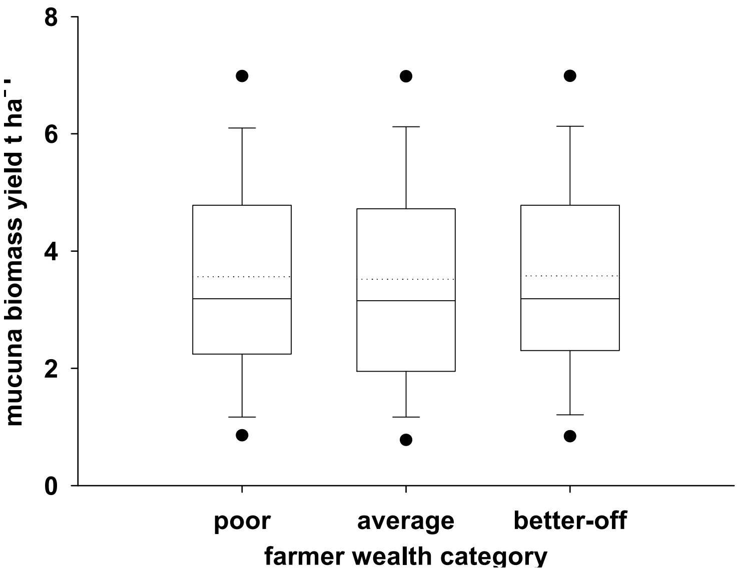

Figure 5.3 Mucuna biomass yield under three farmer wealth categories poor, average and better-off. Legends are the same as for figure 5.1.Maize grain water productivity

Maize grain water productivity (WP_{grain}) was substantially higher in the MMR treatment compared to the FP and MN treatments across all farmer categories (Figure

5.4 a-c). The FP treatment had the lowest WP_{grain}. Grain water productivity varied over the 30-year simulation period, with values ranging from less than 0.2 to more than 1.1 kg m^{-3} across treatments and wealth categories. In the MMR treatment, WP_{grain} could exceed 0.46, 0.47 and 0.49 kg m^{-3} in 75% of the simulated years for the poor, average, and better-off farmer categories, respectively. At a probability of exceedence of 75%, WP_{grain} was 0.20, 0.26 and 0.25 kg m^{-3} in the FP treatment for poor, average and better-off farmer categories, respectively. The results also showed that it is possible to attain higher WP_{grain} values in some years. For example, in 30% of the simulated years, WP_{grain} could exceed 1.0 kg m^{-3} in the MMR treatment across all wealth categories. The highest attainable WP_{grain} values in the FP treatment were 0.69, 0.79 and 0.79 kg m^{-3}, while in the MN treatment were 0.72, 0.90 and 1.05 kg m^{-3} for the poor, average and better-off farmer categories, respectively. Highest attainable WP_{grain} in the MMR treatment was 1.25, 1.36 and 1.41 kg m^{-3} for the poor, average and better-of farmer categories, respectively

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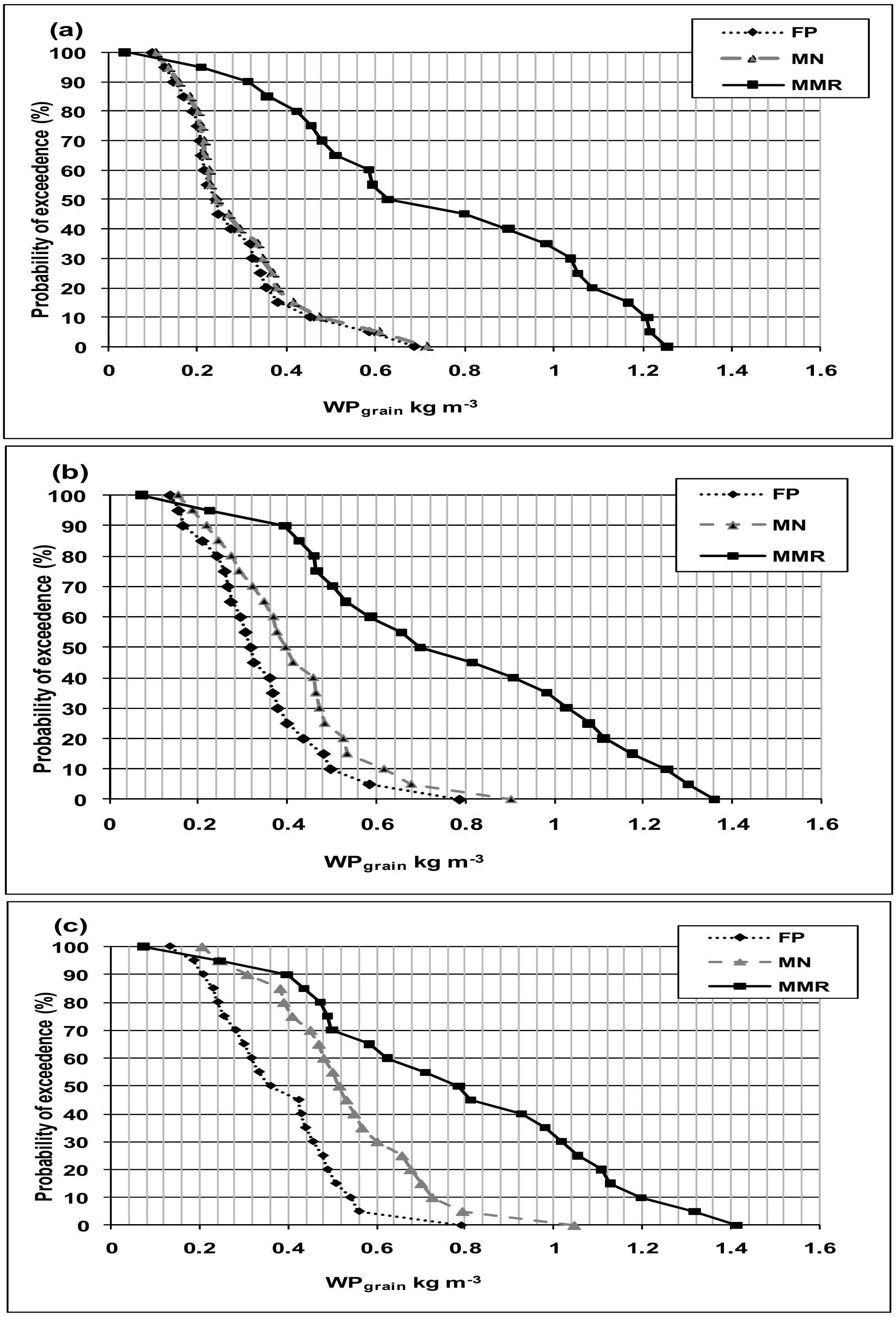

Figure 5.4 Effects of soil fertility management on maize grain water productivity (WP_{grain}) under farmer wealth categories (a) poor, (b) average and (c) better-off, simulated over a period of 30 years. FP = farmer practice; MN = manure; MMR = maize-mucuna rotation.

5.3.2 Soil nitrate nitrogen

Soil nitrate nitrogen (NO_3_N) in the soil profile averaged for each month across the simulated 30 years was substantially affected by the different fertility treatments (Figure 5.5 a-c). Soil NO_3_N was lowest under the FP treatment across all farmer categories. In the poor farmer category, there were minor differences between soil NO_3_N under the FP and MN treatments. For the average farmers, soil NO_3_N in the MN treatment was slightly higher than that of the FP treatment from October to November. In the better-off farmers, soil NO_3_N was 33% higher under the MN treatment as compared to the FP treatment, during the same period. Simulated soil NO_3_N values were highest in November and December across all treatments and farmer categories. The highest soil NO_3_N in the FP treatment was 4.8, 4.9 and 5.7 kg ha^{-1}, while in the MN treatment it was 5.0, 5.8 and 8.5 kg ha^{-1} and under MMR treatment 81.0, 74.0 and 53.2 kg ha^{-1} for the poor, average and better-off farmers, respectively. The MMR treatment showed the highest soil NO_3_N across all wealth categories. For all wealth categories, a 6- to more than 15-fold soil NO_3_N was simulated for the MMR treatment compared to the FP and MN treatments.

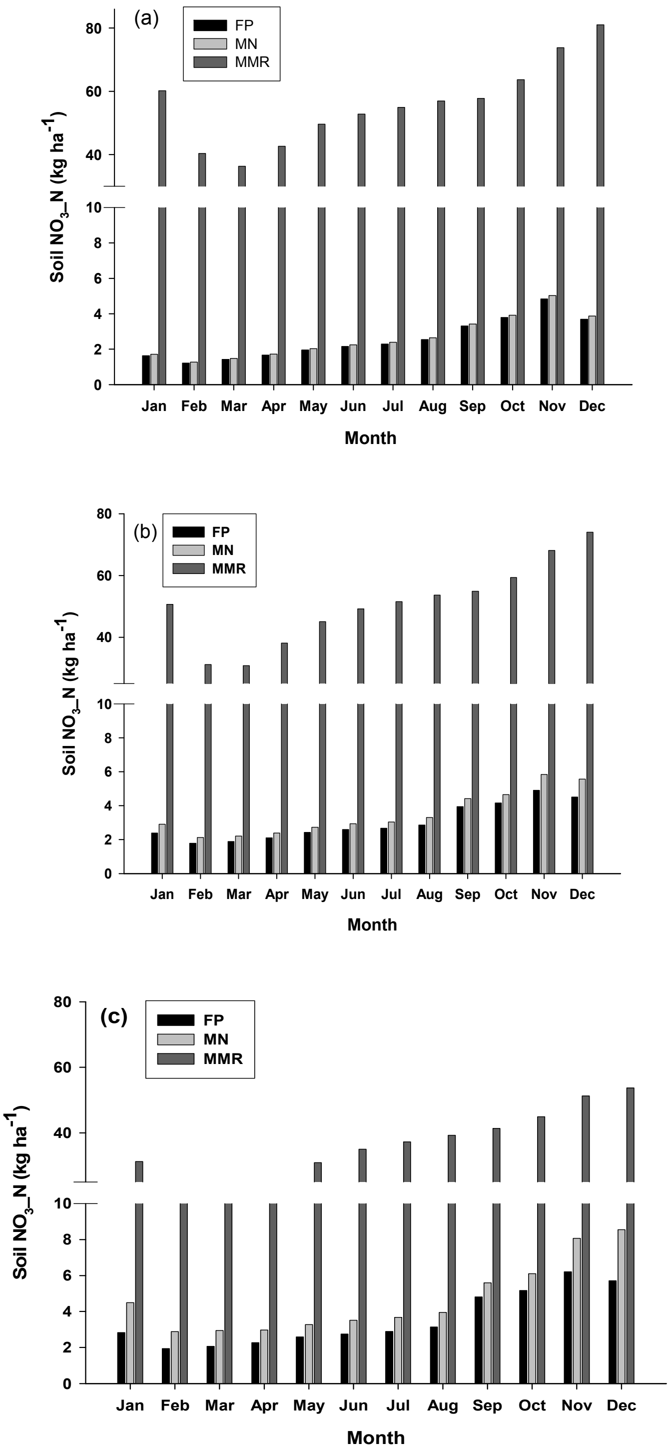

Figure 5.5 a-c Soil nitrate nitrogen (NO_3_N) averaged for each month for the simulated 30 years for the farmer wealth categories (a), poor, (b) average, and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation.

5.3.3 Dynamics of soil total nitrogen

There were pronounced increases and decreases in TN over the simulated 30 years, for all treatments and farmer categories (Figure 5.6 a-c). The FP and MN treatments showed a substantial decrease in TN over time. For the poor farmers, TN under the FP and MN treatments decreased at an almost similar rate as compared to that in the better-off farmers, where TN under manure decreased at a lesser rate than that under the FP treatment. Soil TN decreased from 3.7 t ha^{-1} to 3.4 t ha^{-1} in both FP and MN treatments in the poor farmer category. A substantial decrease was also exhibited in the average farmer category, where initial TN was 4.1 t ha^{-1} and final TN was 3.7 t ha^{-1} in the FP treatment and 3.8 t ha^{-1} in the MN treatment. In the better-off farmer category, initial TN was 4.4 t ha^{-1} and final TN was 3.8 and 4.1 t ha^{-1} under the FP and MN treatments, respectively. Under the MMR treatment there was a marked increase from 3.7 to 4.3 t ha^{-1} in the poor farmer category, whilst under the average farmer category, there was a slight increase from 4.1 to 4.4 t ha^{-1}. Although there were variations across the years, soil TN in the MMR treatment for the better-off farmer category, was maintained as there were no substantial changes over the years. Generally, the MMR treatment improved soil TN across all farmer categories.

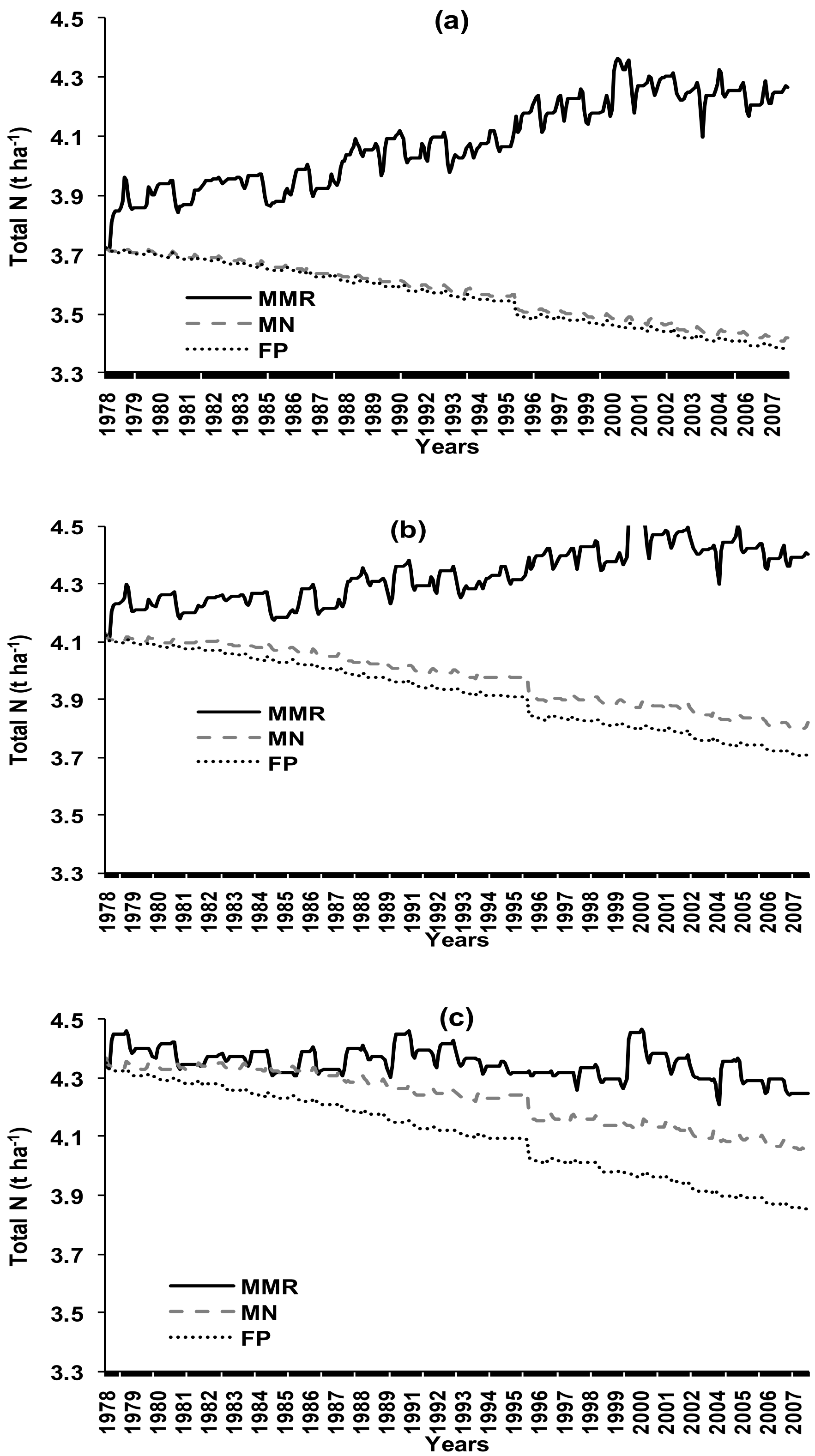

Figure 5.6 a-c Dynamics of soil total nitrogen (TN) in the soil profile (0-70 cm) simulated over 30 years for the farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation.

5.3.4 Dynamics of soil organic carbon

Soil organic carbon (SOC) followed a pattern almost similar to that of total nitrogen as it was also influenced by treatment and wealth category over the simulated 30 years in the top 30 cm of the soil profile (Figure 5.7 a-c). There were marked increases and decreases in SOC across treatments and farmer categories. In the poor farmer category there were no differences in the rate of SOC decrease under the FP and MN treatments over the years. For the average farmer category, there were slight differences in the rate of change under the FP and MN treatments, while for the better-off farmers there were marked differences in the rate of SOC decrease under the FP and MN treatments over the years. Soil organic carbon decreased from 18.2 t ha^{-1} to 17.5 t ha^{-1} in both FP and MN treatments for the poor farmer category. There was also a substantial decrease for the average farmer category, where initial SOC was 21.0 t ha^{-1} and final 19.8 t ha^{-1} under the FP and 20.7 t ha^{-1} under the MN treatments. In the better-off farmer category, initial SOC was 22.3 t ha^{-1} and final SOC 20.4 and 21.7 t ha^{-1} under the FP and MN treatments, respectively. In the MMR treatment, there was a marked increase in SOC from 18.2 to 25.1 t ha^{-1} for the poor category, whilst for the average category there was an increase from 20.9 to about 24.7 t ha^{-1}. Although there were variations over the years, SOC under the MMR treatment for the better-off remained almost unchanged at 22.4 t ha^{-1}. Generally, the MMR treatment improved SOC for the poor and average farmer categories, while for the better-off farmer category; the MMR treatment maintained constant values of SOC over time.

Trends in SOC and TN under different treatments among the three farmer categories over time were analyzed (Table 5.3). There were variations in losses and gains of SOC in the systems under the different treatments. Losses under FP were the highest compared to the other two treatments across all farmer categories. Losses of 74.1, 50.7 and 24.7 kg $ha^{-1}yr^{-1}$ were simulated for the poor, average and better-off farmer categories respectively. Under the MN treatment, there were higher losses of 26.0 kg $ha^{-1}yr^{-1}$ in the average farmer category compared to the better-off and poor famer categories, where losses were 20.4 and 17.0 kg ha^{-1} yr^{-1}, respectively. Under the MMR treatment, there were SOC increases of 194.8 kg ha^{-1} yr^{-1} in the poor farmer category, while these were 110.0 and 2.6 kg $ha^{-1}yr^{-1}$ for the average and better-off farmer categories, respectively.

Total soil N under the different treatments showed both negative and positive balances over the simulation period. Generally, there were losses across all treatments except under the MMR treatment for the poor and average farmer categories. Losses under the FP treatment were highest for the better-off farmer category, with an average loss of 16.5 kg $ha^{-1}yr^{-1}$ as compared to the average and poor which had 13.5 and 11.1 kg ha^{-1} yr^{-1}, respectively. Losses under manure treatment were almost similar for the average and better-off farmers, with average losses of 10.5 and 9.6 kg $ha^{-1}yr^{-1}$, respectively. Losses under the MMR treatment were lowest for the better-off farmer categories as compared to losses under FP and MN treatments in this category. There was a positive N balance under the MMR treatment for the poor and average farmer categories, with mean annual gains of 14.2 and 6.1 kg $ha^{-1}yr^{-1}$, respectively.

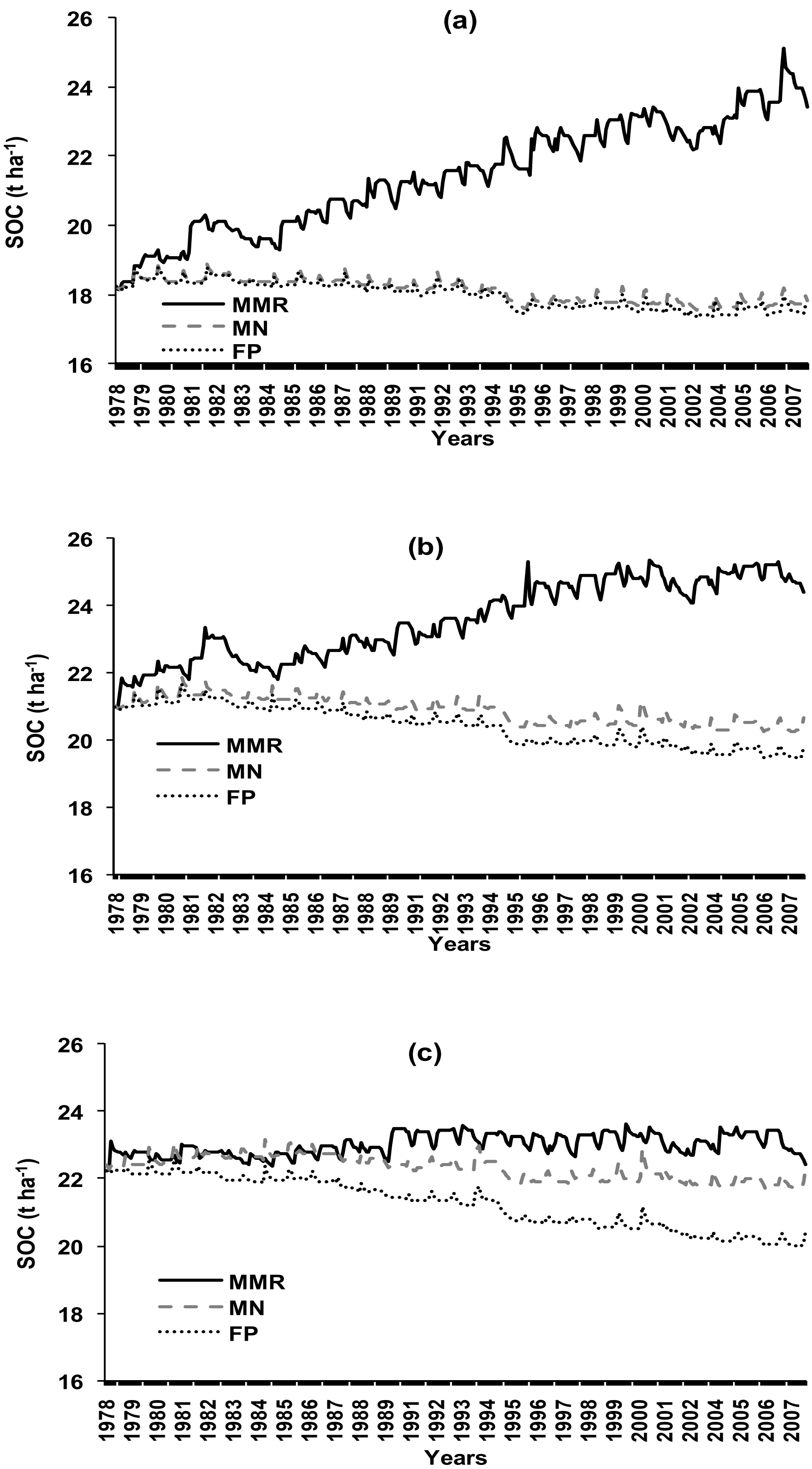

Figure 5.7 a-c Dynamics of soil organic carbon (SOC) in the top 30 cm of the soil profile simulated over 30 years under three fertility treatments for the farmer wealth categories (a) poor, (b) average and (c) better-off, FP = farmer practice, MN = manure, MMR = maize-mucuna rotation.

Table 5.3 Trends in soil organic carbon (SOC) and total soil nitrogen (TN) under three treatments and farmer wealth categories. Soil organic carbon in top 30 cm of the soil profile whilst total nitrogen in soil profile upto 70 cm depth. FP= farmer practice; MN= manure; MMR= maize-mucuna rotation.

Treatment	SOC (kg $ha^{-1}yr^{-1}$)	TN (kg $ha^{-1}yr^{-1}$)
	Better-off	
FP	-74.1	-16.5
MN	-20.4	-9.6
MMR	2.6	-6.0
	Average	
FP	-50.7	-13.5
MN	-26.0	-10.5
MMR	110.0	6.1
	Poor	
FP	-24.7	-11.1
MN	-17.0	-10.2
MMR	194.8	14.2

5.3.5 Nitrogen and water stress factors

Both rainfall and nitrogen (N) play an important role in crop production. Average annual rainfall was 534 mm across the simulated 30 years; highest rainfall was recorded in 2000 and lowest in 1992 (Figure 5.8). Years with high rainfall did not always coincide with high yields. For example, 1985 and 1988, where annual rainfall was 624 and 811 mm, respectively, grain yields were slightly above 1 t ha^{-1} under the MMR treatment. There were also years with below-average annual rainfall but had very high yields, e.g., 1981 and 1999 where annual rainfall was 283 and 402 mm, respectively and average grain yield was above 3 t ha^{-1} under the MMR treatment. To determine the effects of rainfall and N on crop production under the different treatments, an analysis of soil N and water stress factors during maize growth periods was done for the worst years (Figure 5.9 and 5.10), normal (Figure 5.11 and 5.12) and best years (Figure 5.13 and 5.14) . Years were categorized according to year performance indicated by APSIM in the maize yield simulation from 1978 to 2008 and randomly selected within the categories. Selected worst years were 1980, 1982, and 1992, normal years were 1986, 1994 and 2002, and best years were 1996, 2000 and 2004.

The simulated soil N and soil water (SW) stress factors predicted for the worst years showed that crops under the FP and MN treatments generally experienced slight to severe N stresses from approximately 10 days after sowing (DAS) until crop maturity across all wealth categories (Figure 5.9 and 5.10). In the worst years, N stress below 0.5 was experienced by crops under the FP and MN treatments from approximately 43, 46 and 47 DAS for the poor, average and better-off farmer categories, respectively. There was no critical N stress under the MMR treatment across all farmer categories in the worst years. Soil water stress below 0.5 was experienced by crops under the MMR treatment across all wealth categories at approximately 60 DAS. No SW stress was simulated for crops under the FP and MN treatments for the poor and average farmer categories. Slight SW stress was simulated for crops under the MN treatments for the better-off farmer category from approximately 76 DAS.

During the normal years, N stresses below 0.5 were experienced by crops under the FP and MN treatments at approximately 48 and 49 DAS for the poor and average farmer categories, respectively, while for the better-off farmer category, N stress was experienced around 57 and 71 DAS under the FP and MN treatments, respectively (Figure 5.11 and 5.12). No N stress was simulated under the MMR treatment for the poor and average farmer categories but there was low N stress under the MMR treatment for the better-off farmer category. No SW stress was experienced by crops under the FP and MN treatments for the poor and average farmer categories, but there was slight SW stress under the MN treatment for the better-off farmer category. During the normal years, SW stress under the MMR treatment were experienced around 84 DAS across all farmer categories.

In the best years, simulations showed N stress under the FP and MN treatments across all wealth categories while under the MMR treatment no N stress below 0.5 was experienced across all farmer categories (Figure 5.15 and 5.16). Only minimal SW stress was experienced by crops under the MMR treatment across all farmer categories. Generally, N stress was below 0.5 and there was no SW stress under the FP and MN treatments across all farmer categories in all years. Under the MMR treatment, there was no N stress below 0.5, but SW stress was below 0.5 across all farmer categories during the worst and normal years. In the best years there was no N and SW stress experienced by crops across all farmer categories under the MMR treatment.

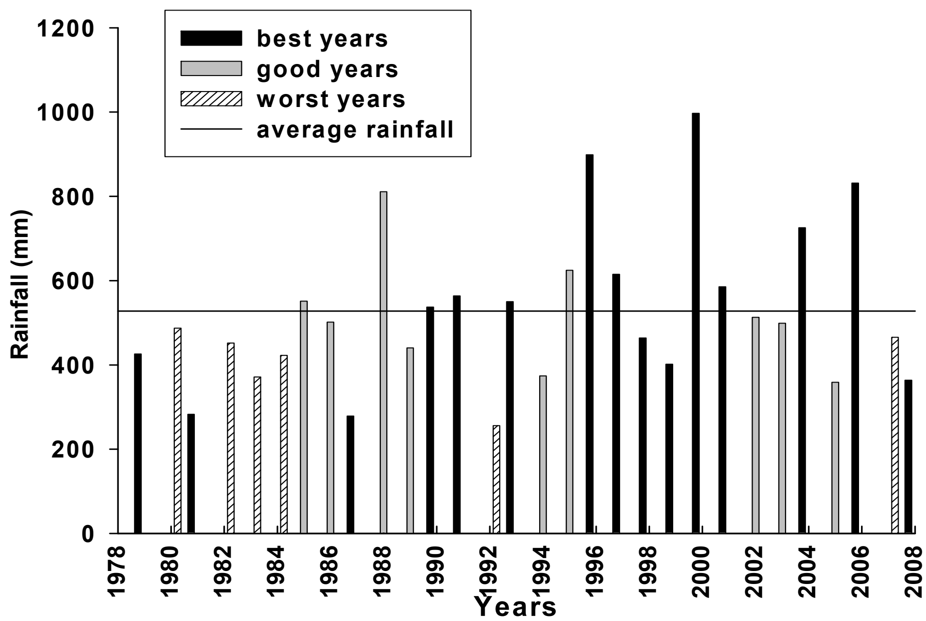

Figure 5.8 Annual rainfall and year performance indicated by APSIM for maize grain yield simulated from 1978 to 2008 under different treatments and across farmer wealth categories. Worst years = yields below the 25 percentile, normal years = yields within 50 percentile, and best years = yield above 75 percentile.

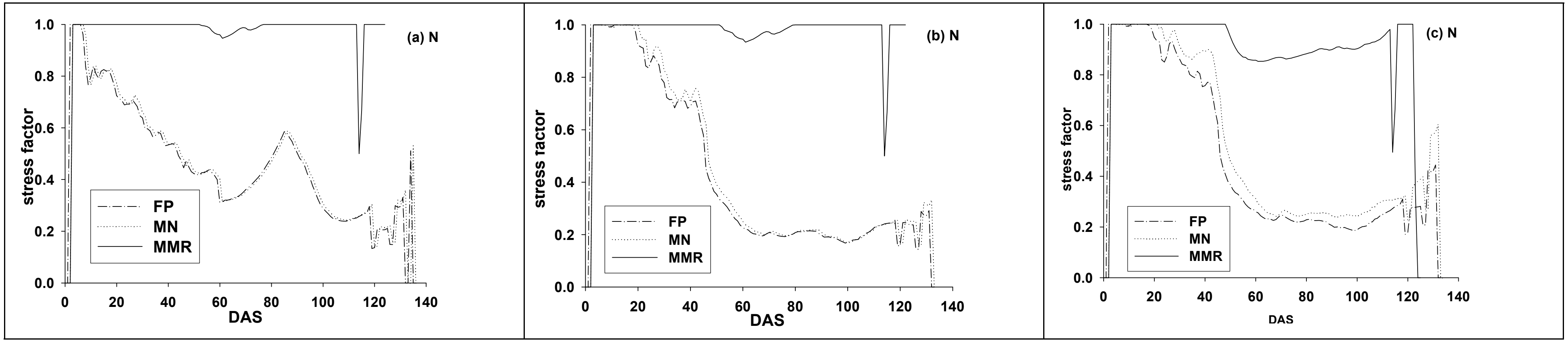

Figure 5.9 a-c Simulated nitrogen stress factors (1 = no stress; 0 = extreme stress) during selected worst years (1980/82/92) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation, N = soil nitrogen, DAS = days after sowing

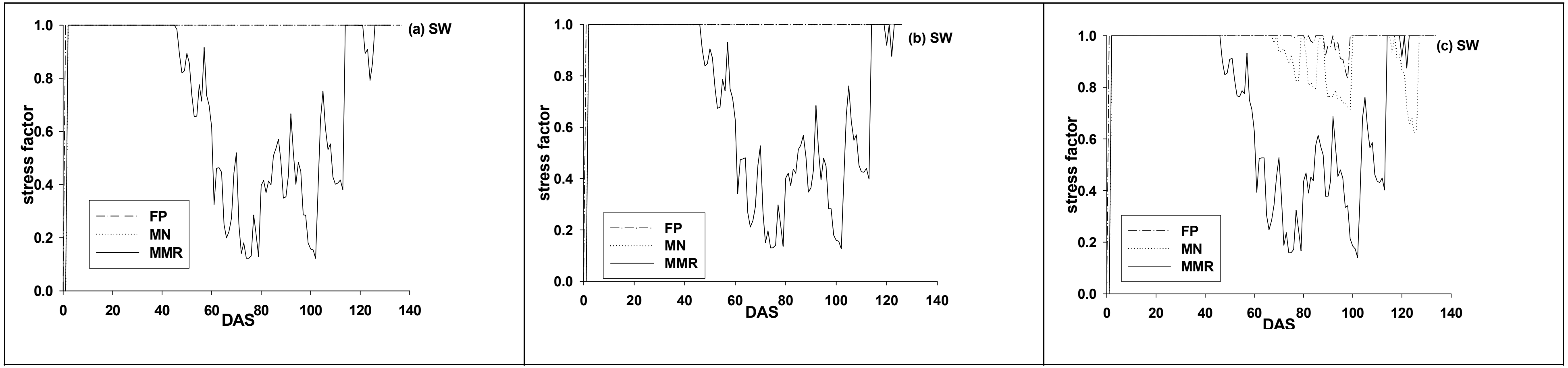

Figure 5.10 a-c Simulated water stress factors (1 = no stress; 0 = extreme stress) during selected worst years (1980/82/92) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize- mucuna rotation, SW = soil water, DAS = days after sowing

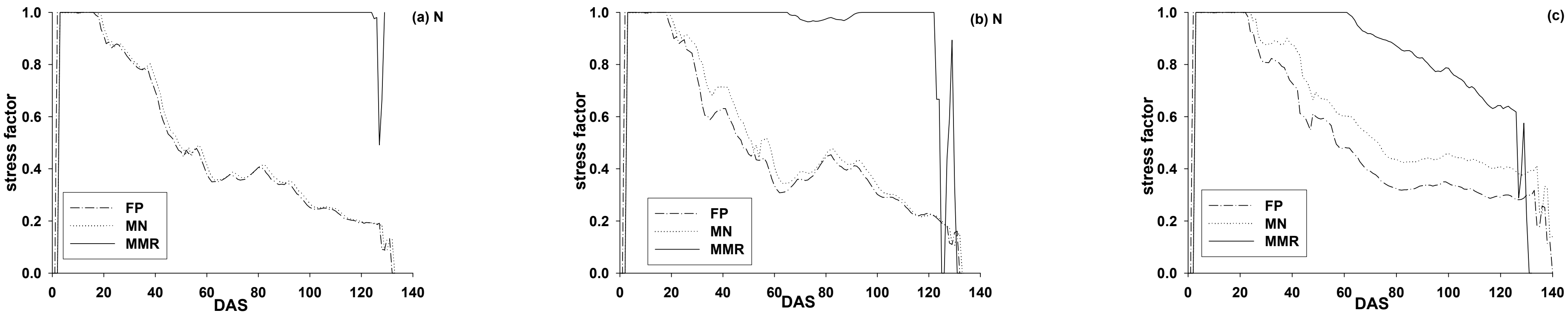

Figure 5.11 a-c Simulated nitrogen stress factors (1 = no stress; 0 = extreme stress) during selected normal years (1986/94/2002) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation, N = soil nitrogen, DAS = days after sowing

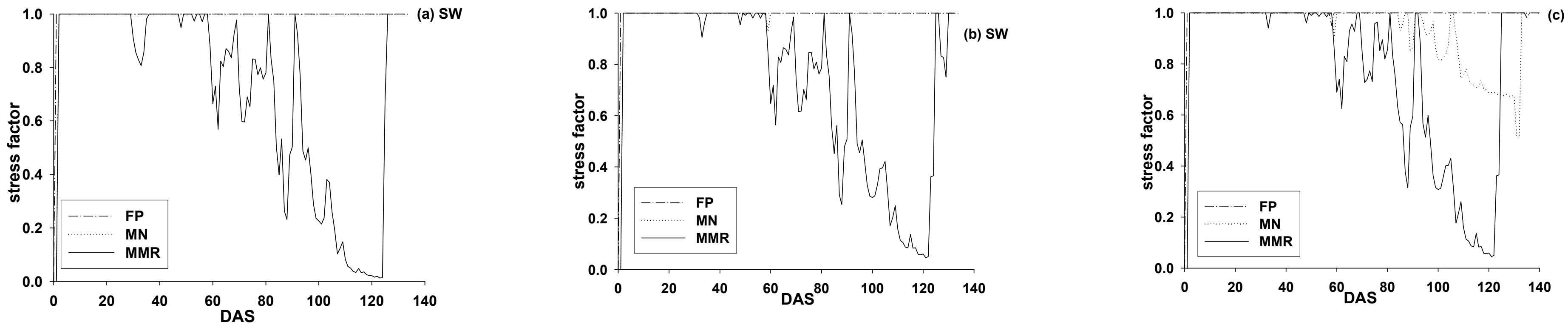

Figure 5.12 a-c Simulated water stress factors (1 = no stress; 0 = extreme stress) during selected normal years (1986/94/2002) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation, SW = soil water, DAS = days after sowing

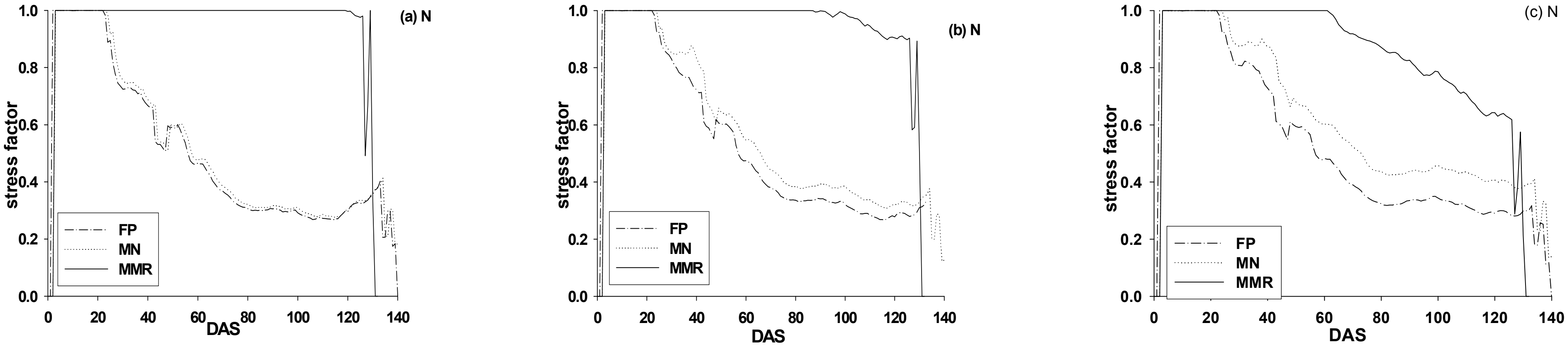

Figure 1.13 Simulated nitrogen stress factors (1 = no stress; 0 = extreme stress) during selected best years (1996/2000/04) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation, N = soil nitrogen, DAS = days after sowing

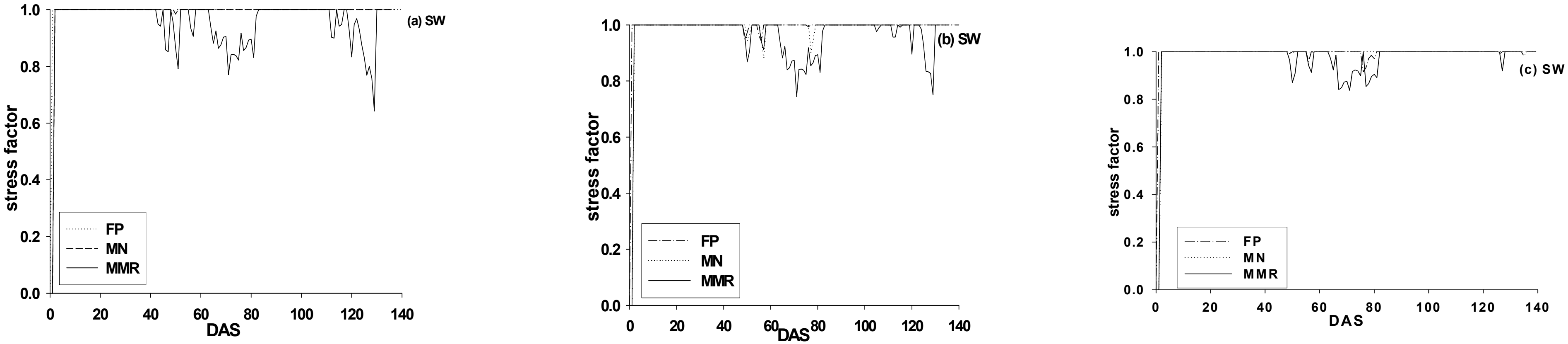

Figure 1.14 Simulated water stress factors (1 = no stress; 0 = extreme stress) during selected best years (1996/2000/04) for maize crop under three fertility treatments for farmer wealth categories (a) poor, (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation, SW= soil water, DAS = days after sowing.

5.4 Discussion and conclusions

5.4.1 Maize and mucuna biomass yield

In the rain-fed semi-arid tropics of Zimbabwe, the agro-ecosystems are characterized by erratic rainfall patterns during the growing season. Low water holding capacity of the predominant sandy soils coupled with low soil organic matter and high evapotranspiration further contribute to soil moisture limitation during the crop growing period. Crop production is monoculture and cereal based with minimal application of soil fertility amendments. The simulated maize grain yields showed variations across seasons, treatments and farmer wealth category. There were pronounced differences in maize grain yield across treatments and wealth categories. Maize yields were low under the FP treatment, showing the negative effects of non-application of soil amendments. The effects of differences in initial soil N and organic carbon (OC) were also evidenced by yield variations under the FP treatment across farmer categories. Initial soil N and OC were higher in the average and better-off farmer categories leading to higher yields compared to the poor farmer category. Maize yield under manure treatment in the poor category was lowest compared to all manure treatments, which can be attributed to the low manure quantities applied. In the poor farmer category, the application rate was 411 kg ha^{-1} and the manure N content was 0.89%. This means that about 4 kg of nitrogen was applied in the poor farmer category as compared to 17 and 40 kg ha^{-1} for the average and better-off farmer categories, respectively.

Under the MMR treatment, simulated yields were substantially increased across all wealth categories, but there was also high inter-annual variability. Lowest maize grain yields were below 0.5 t ha^{-1}, and highest yields were above 4 t ha^{-1}. For maize stover the lowest yields were about 1.5 t ha^{-1}, and the highest about 8 t ha^{-1}. The high yields under the MMR treatment can be attributed to a combination of crop residues, manure and N fixation by the legumes. After harvesting, crop residues were removed from the field at varying rates to be used as dry season livestock feed. The poor farmer category benefited more from incorporated crop residues, as only 30% was removed. On average, 3.1 t ha^{-1} yr^{-1} of residues were left in the field annually in the poor farmer category, while in the average farmer category about 2.3 t ha^{-1} yr^{-1} were left in the field. Yields in the average farmer category were improved by a combination of manure and crop residues, which contributed about 70 kg ha^{-1} of soil NO_3-N at the beginning of the cropping season. The better-off farmer category benefited from N fixation combined with manure, which contributed about 50 kg ha^{-1} of soil NO_3-N. The results showed that in smallholder mixed crop-livestock systems, the conventional monoculture cropping with low application of soil fertility amendments can be significantly improved by incorporating forage legumes in rotation with cereal crops. Mucuna was chosen in this study for its adaptability performance and potential to improve soil fertility, crop yield (Nyambati 2002; Maasdorp et al. 2004) and livestock supplementary feed in semi-arid areas including Zimbabwe (Maasdorp and Titterton 1997). In this study, the rotation had positive effects on both maize grain and stover yields. Mucuna biomass was also high with an average yield of 3.5 t ha^{-1}. The highest yield of more than 5 t ha^{-1} was attained in six out of 30 simulated years, which is similar to what has been reported for smallholder farming systems in sub-humid areas of Zimbabwe (Waddington et al. 2004). The use of forage legumes in rotation with cereal crops has been reported to have beneficial effects not only in the overall grain yield production, but also in the chemical and physical properties of the soil (Nyambati 2002; Waddington et al. 2004; Alvaro-Fuentes et al. 2009).

5.4.2 Maize grain water productivity

Simulations using the APSIM model revealed that in the study area WP_{grain} is adversely affected to a great extent by low soil fertility. Interventions that can improve soil fertility are likely to have positive impacts on WP. Potential WP_{grain} of the rain-fed semi-arid tropics is 0.9 to 1.2 kg m^{-3} (Rockström et al. 2003; Cai and Rosegrant 2003). In this study, average WP_{grain} under the MMR treatment was 0.75 kg m^{-3}. The higher values ranging between 1.3 and 1.4 kg m^{-3} were achieved in only 3 years of the simulated 30 years, while 0.9 kg m^{-3} was achieved in 12 years. This shows that there is scope to improve WP on smallholder farmers with increases in soil fertility. Average mucuna WP_{grain} was 1.23 kg m^{-3} across all farmer categories. Mucuna WP was higher than maize grain WP_{grain} which was on average 0.34, 0.42 and 0.75 kg m^{-3} under the FP, MN and MMR treatments, respectively. This is because mucuna WP is calculated using total above-ground biomass. In mixed crop-livestock systems, maize is used as feed and food. Water productivity of maize calculated using total above-ground biomass was

0.92, 1.15 and 2.31 kg m^{-3} under the FP, MN and MMR treatments respectively. The results show that with improved soil fertility, maize, exhibited higher WP than mucuna.

To understand the effects of rainfall and soil fertility in terms of N on crop productivity under the different treatments, an analysis of N and SW stress factors during maize growth periods was done for the worst, normal and best years. Rainfall was a limiting factor in the MMR treatment while soil N was a limiting factor in the FP and MN treatments across all farmer categories. Low soil NO_3-N in the FP and MN treatments caused N stress for maize crop during all selected years (worst, normal and best) across all farmer categories. Nitrogen stress below 0.5 was experienced from the floral initiation stage until crop maturity. It can be concluded that under low fertility conditions in the semi-arid areas, maize production is more limited by fertility than soil water as crops under the FP and MN treatments did not experience SW stress in all years.

On the other hand, high soil NO_3-N (>50 kg ha^{-1}) in the MMR treatment showed no N stress below 0.5 during all years across all farmer categories. However, water was limiting during the worst and normal years. Water stress below 0.5 was experienced by crops between the floral initiation and flag leaf stages during the worst years and at the flowering stage during the normal years. On average there was a difference of about 24 days between the onset of water stress during the worst and normal years. Water stress experienced by the crops under the MMR treatment lead to a reduction in the harvesting index (HI). Under the FP treatment, HI was 0.34, 0.42 and 0.38 while under the MN treatment it was 0.33, 0.42 and 0.39 during the worst, normal and best years, respectively. Under the MMR treatment, HI was 0.11, 0.24 and 0.40 during the worst, normal and best years, respectively. Low HI under the MMR treatments during the worst and normal years can be attributed to water limitations. Increasing soil N increases crop growth and biomass production, which means higher transpiration to produce the biomass, and thus the soil water becomes depleted more quickly. This can result in water stress during grain setting if there is no rainfall event during that period, and thus leading to reduced grain number. Soil water stress was experienced during the critical period for grain setting (flowering stage). This is also evidenced by low variability in stover and mucuna biomass yield across the years as compared to grain yield. No soil water stress was experienced during the best years. It is therefore important to note that when soil fertility is improved in these areas, rainfall becomes the limiting factor.

5.4.3 Soil organic carbon and total nitrogen

The simulation results showed that the conventional FP treatment has negative effects on both SOC and TN content over time. Soil organic carbon and TN were substantially decreased mainly because no organic soil amendments were applied. Losses of SOC ranged from 17 to 74 kg ha^{-1} yr^{-1}, while TN losses ranged from 9 to 16 kg ha^{-1} yr^{-1}. This resulted in losses of SOC ranging from 741 to 2223 kg ha^{-1} yr^{-1} over the 30 years. For soils that are already impoverished, these are significant losses and detrimental to future crop production. The manure treatment also had negative effects on SOC and TN across wealth categories due to the low quantities of manure available to smallholder farmers; both quality and quantity are low. Recommended manure application rates are 10 t ha^{-1} yr^{-1} (Mugwira and Shumba 1986). The poor farmers can only apply 0.4 t ha^{-1} yr^{-1}, but the average and better-off farmer categories 1.9 and 4.4 t ha^{-1} yr^{-1}, respectively. These quantities cannot sustain a maize grain yield of more than 1 t ha^{-1}, as NO_3-N ranged between 4 to 8 kg ha^{-1}. The low amounts of NO_3-N can be attributed to declining SOC under the FP and MN treatments, resulting in low crop yields.

The MMR treatment had varied effects on both SOC and TN in the three farmer categories. In the poor and average farmer categories, both TN and SOC were substantially increased over the years. The positive effects were attained mainly because 70% of harvested crop residues were incorporated into the system in the poor category. In the average category, positive effects on SOC and TN can be attributed to a combination of 1.9 t ha^{-1} yr^{-1} of manure and 2.3 t ha^{-1} yr^{-1}of crop residues. This combination increased SOC by 3.3 t ha^{-1} in the top 30 cm soil profile and TN by 0.2 t ha^{-1} to a depth of 70 cm over 30 years. The MMR treatment showed a steady and constant maintenance of SOC but there were losses of TN up to 6 kg ha^{-1} yr^{-1} for the better-off farmer category. This can be attributed to the lack of residue incorporation, as all crop residues were removed from the system. Soil organic carbon was steadily maintained under the MMR treatment, even though all residues were removed from the system. There were minimal increases in SOC of about 3 kg ha^{-1} yr^{-1}. Benefits could be obtained from a combination of manure and below ground-biomass and senesced material. It is important to note that there is lack of experimental data showing long-term effects of conventional and cereal-legume rotation on SOC and TN dynamics in smallholder farming systems (Zingore 2006; Probert 2007). Sanchez et al (1997) reported N losses of up to 660 kg ha^{-1} in a period of about 30 years from an estimated 200 million ha of cultivated land in 37 African countries. In this study the simulated SOC and TN trends under the FP are very similar to the prevailing situation in smallholder farming systems in the semi-arid tropics of Africa (Sanchez et al. 1997; Waddington et al. 2004; Probert 2007). Soil organic carbon is the backbone of soil organic matter, which affects soil quality because it is a nutrient reservoir and positively influences soil properties such as cation exchange capacity, aggregation, soil bulk density, microbial activity and soil tilth (Coulter et al. 2009). McCown and Jones (1992) referred to continual loss of SOC in smallholder farming systems as “the poverty trap”. To get farmers out of this poverty trap, technology interventions that can improve SOC should be developed. The maize-mucuna rotations have the potential to improve $WP_{grain,}$, soil fertility and livestock feed. This technology can be tested under smallholder farming systems in the semi-arid areas of Zimbabwe. It can also be tested under sub-humid areas, as performance of the technology was high under non-water-limiting conditions.

5.5 Appendix 1 Properties of the soil used in this study

	Soil Layer (cm)					
Parameter	0-15	15-30	30-45	45-60	60-75	75-100
Airdry (mm/mm)	0.03	0.07	0.09	0.09	0.09	0.09
Crop_LL(mm/mm)	0.06	0.10	0.13	0.13	0.18	0.22
LL* 15 (mm/mm)	0.06	0.10	0.13	0.13	0.18	0.22
DUL (mm/mm)	0.16	0.18	0.19	0.20	0.22	0.24
SAT (mm/mm)	0.41	0.41	0.41	0.37	0.36	0.34
Bulk density (g cm^{-3})	1.43	1.42	1.42	1.55	1.55	1.61
cn2-bare	85					
u	6					
cona	3.5					
Soil carbon : nitrogen	12					

* LL = volumetric water content at lower limit of extraction of water by crop; DUL = volumetric water content at drained upper limit; SAT = volumetric water content at saturation; cn2-bare = curve number for run-off from bare soil; u and cona the coefficients for 1st and 2nd stage soil evaporation.

6 POTENTIAL CONTRIBUTION OF STOVER AND MUCUNA TO DRY SEASPN FEED AND IMPLICATIONS TO LIVESTOCK WATER PRODUCTIVITY

6.1 Introduction

Most farming systems in the Semi-Arid Tropics of Sub-Saharan Africa (SATSSA) integrate crop and livestock production. The principal cereal crops are pearl millet, sorghum, maize, and household livestock holdings vary from a few to hundreds of head per household with varying ratios of cattle, sheep, donkeys, camels and goats (Powell et al*,* 2004). Livestock play an important role in these farming systems, as they offer opportunities for risk coping, farm diversification and intensification and provide significant livelihood benefits to the rural poor (Williams et al. 2002). Animals are kept for complimenting cropping activities through the provision of manure for soil fertility maintenance, draft power for cultivation and transport, and for cash and food (Williams et al. 2002; Powell et al. 2004). Natural pasture provides the basic feed for ruminant animal production (Undi et al. 2000; Woyengo et al. 2004; Hall et al. 2007*).* Grass biomass and quality is low during the dry season with protein content dropping from 120-160 g crude protein kg^{-1} dry matter (DM) in the growing season to as low as 10-20 kg^{-1} DM in the dry season (Baloyi et al. 1997; Maasdorp and Titterton, 1997; Mpairwe 2005). This causes livestock dry season feed levels to be critically low in terms of quantity and quality consequently affecting both the growth and reproductive performance of the livestock.

The SATSSA are experiencing an enormous increase in demographic pressure. To meet the food demands of the growing population, farmers are forced to extend cropping activities to marginal lands, rangelands and forest areas resulting in livestock marginalization, reduced fallow periods and ecological degradation (Powell et al. 2004; Abegaz 2005). As a result of the population growth, the demand for animal products is increasing by 2.5 to 4% per year (Peden et al. 2007). In the face of climate change and environmental degradation, it is imperative that livestock systems are transformed and intensified along productive and sustainable pathways (Peden et al. 2007). The challenge is that livestock require a great deal of water, not for drinking but for their feed, as they “eat” up to 100 times more water than they drink. The water requirements of animals vary with type of feed management, slaughter, processing and packing of products (Tadesse and Mammo 2007).

Recently, it has been recognized that livestock feed production depletes large amounts of global fresh water, and consequently, the concept of increasing livestock water productivity (LWP) is emerging (Peden et al. 2006; Steinfeld et al. 2006). Peden et al (2007) define livestock water productivity as the ratio of livestock-related products and services (the overall benefits) to the water depleted producing these. The major components that can directly affect LWP have been identified to be the type, quality and amount of forage/feed crops produced, amount of water used to grow these feeds, productivity level of the animal using these feeds, which can be affected by the breed, animal health and management conditions, the quality of veterinary services and various socio-economic incentives (Peden et al. 2007). One key strategy for increasing LWP lies in selecting feed sources that use relatively little water or that use water that has little value for other human needs or for support of ecosystem services (Peden et al. 2009). It has been argued that crop residues are the single most important feed resource in many livestock production systems in developing countries, and that increasing their contribution to livestock feeding needs to be linked to improving their fodder quality (Blümmel et al. 2009). Cereal crop residues with low nutrient content and digestibility form a major source of available crop residues in smallholder farming systems. The quality of cereal crop residues has been improved by mixing them with legumes or by treatment with alkali, which enhances quality, intake and digestibility (Bwire and Wiktosson 2002; Woyengo et al. 2004).

The use of crop residues as adjuncts to livestock feed shortages especially during the dry season has been reported by a number of researchers in Zimbabwe (e.g., Ngongoni et al. 2007; Mapiye et al. 2009). However, not much research work has been done to quantify the feed deficits and the extent to which crop residues can be used to alleviate the dry season livestock feed shortages. Given the socio-economic status of smallholder farmers, it is important that interventions aimed at increasing livestock productivity, while enhancing the well-being of farmers (Ngongoni et al. 2007) and using minimal external inputs, must be developed. The study therefore had several objectives. First, to assess farmer perception on dry-season feed shortage periods and alternative feed and fodder resources used. Second, to evaluate potential feed demand

and supply of natural pastures and potential feed deficits for livestock in three farmer wealth categories over a one year period. Third, to evaluate the potential contribution of maize stover and mucuna biomass to livestock feed requirements during the dry season and the implications for livestock water productivity.

6.2 Materials and methods

6.2.1 Community and household interviews

Participatory rural appraisals (PRA) and structured questionnaires (pre-tested) through interviews were used to collect qualitative and quantitative information of livestock production in Nkayi District i.e., data on farmer land and livestock holdings (Chapter 2). Three farmer wealth categories were established (poor, average and better-off), and the livestock herd composition for each wealth category was determined. Data on crops grown by different farmers and the area used were also collected. Major livestock production constraints highlighted by the farmers (Chapter 2) include feed and water shortages during the dry season, diseases, and lack of markets and veterinary services. Information on livestock feed management strategies that farmers use to alleviate feed shortages during the dry season was also collected.

6.2.2 Monitoring on-farm livestock weight and milk production

A number of farmers were randomly selected among the livestock farmers for detailed on-farm measurements. The aim was to compare livestock liveweight variations and milk production for the three farmer categories. However, after randomly selecting the farmers, those belonging to the poor category did not own cattle, so cattle liveweight and milk production were not recorded for this category. From the beginning of the cropping season 2008/2009, cattle liveweight and milk production were monitored for 24 farmers. Livestock weights were determined by measuring the hearth girth circumference of cattle at monthly intervals. Measurements were done on 52 and 84 head of cattle from the better-off and average wealth categories, respectively. Milk production was recorded by farmers on a daily basis and measured using measuring cylinders that had been provided for this purpose.

6.2.3 Dry season feed shortages

The forage resources in Nkayi district are held communally and are characterized by low levels of production per unit area and high variability in yields, both within and across years (ICRISAT, survey 2008). In these systems, the individual herd manager has few choices or opportunities to improve the supply of forage to his herd at any given time (Panos et al. 1982). A significant amount of research has been done on annual pasture production (Day et al. 1999; Ngongoni et al. 2007; Mapiye et al. 2009), but there is little data on pasture growth, quantity and quality through the course of the year and over several years. This is important for accounting for within- and between-year variations in pasture production (Moore et al. 2009). With high the variability of feed quality and quantity in smallholder farming systems in the semi-arid tropics of Zimbabwe this is a serious knowledge gap. APSIM was used to simulate daily grass growth to mimic grass production in the smallholder farming systems. The sweet modified sorghum sugargraze variety (Hargreaves pers. commun.) was used on a sandy soil at a planting density of 7 plants m^{-2} to simulate daily grass growth. The meteorological data used were from the Matopos Research Station (Chapter 5).

The model was evaluated using annual grass biomass production measured at the Matopos Research Station (Illius et al. 2003). The biomass was measured from a sandy soil; predominant grass species in the area were *Aristida* spp, *Digitaria pentzii, Cynodon dactylon and Heteropogon contortus*. These species are common in the semi-arid areas of Zimbabwe (Gambiza and Nyama 2000). Matopos Research station is located between 20° 25′ south and 28° 24′ east, while Nkayi district lies between 19° 00′ south and 28° 20′ east. Both sites are characterized by semi-arid climatic conditions with annual rainfall that ranges between 450 and 650 mm. Grass production was simulated for 4 seasons from 1998 to 2002 to match the period of the measured grass production. The model predicted grass production with satisfactory accuracy (Table 6.1). The root mean square error (RMSE) was 336 kg ha^{-1} while the coefficient of efficiency was 0.99. The model underestimated grass production in the growing period 2000/01. Average measured grass biomass production over the four years was 1046 kg ha^{-1} yr^{-1}, while the simulated average was 1213 kg ha^{-1} yr^{-1}. The model was later used to simulate daily grass biomass production (Figure 6.1). Simulations were run on a sandy soil for 30 years from 1978 to 2008 using a weather record collected by the national weather bureau for Matopos Research Station (Chapter 5).

Table 6.1 Comparison of measured and simulated grass production for Matopos area for the period 1998 to 2002.

Year	**Measured grass biomass (kg ha^{-1})**	**Simulated grass biomass (kg ha^{-1})**
1998/99	810	1183
1999/00	1197	1619
2000/01	1239	671
2001/02	936	1318
Mean	**1046**	**1213**

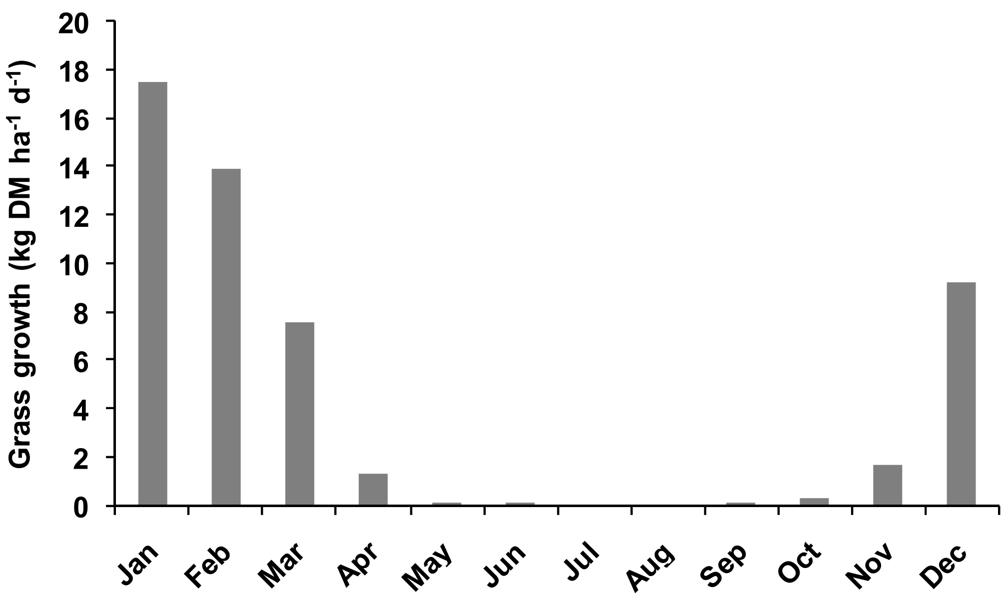

Figure 6.1 Simulated average daily grass growth per month over 30 years 1978-2008 using the APSIM model.

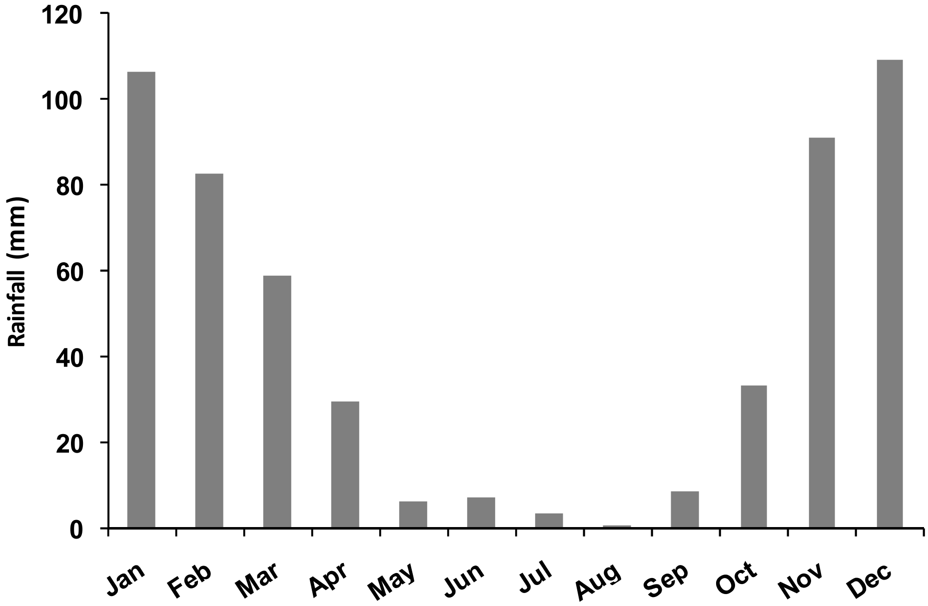

Figure 6.2 Average monthly rainfall for Matopos Research Station from 1978-2008

6.2.4 MLA feed demand calculator

The APSIM model output data on pasture growth were used as input data to the Meat and Livestock Australia (MLA) feed demand calculator. The MLA is a feed calculator that calculates total feed demand of livestock in a given area for each month of the year and compares total demand to the likely supply of pasture (MLA, CSIRO 2008). The calculator was developed to assist livestock producers to measure

- The way in which the numbers and classes of livestock on a property drive the total demand for pasture
- The match (or mismatch) between the supply of and demand for pasture
- The proportion of pasture growth that is eaten by livestock, and
- The weight of beef or sheep produced per hectare.

The model simulates feed shortages when metabolisable energy (ME) supply from pasture is less than the demand for ME by livestock (Moore et al. 2009). Total weight of pasture dry matter summed across months where livestock demand exceeds pasture supply, assuming that 66% of pasture that is in excess of livestock demand is carried over to the next month. The calculation of feed demand by each class of livestock per month is based on how much feed the livestock need to perform, divided by the energy content of the feed according to the equation:

$$Feed\ Demand = \frac{(ME_r)\times(number\ of\ animals)\times(days\ in\ period)}{(ME_p)} \tag{6.1}$$

where ME_r is ME requirement per head per day, and ME_p is ME content of pasture intake.

Although the inbuilt sites and livestock breeds of the calculator are from Australia, the user can specify important site specific data such as:

- Effective grazing area (ha): the total area of pasture available to livestock for the 12-month period.
- Enterprise type: if working with a cattle herd or sheep flock only, the user can choose “cattle only” or “sheep only”. There is also an option to select both cattle and sheep.
- Pasture growth rates: area-specific growth rates for each month are entered in units of kg dry matter per hectare per day.
- Pasture quality: the quality of the pasture is expressed as the average metabolisable energy content of the animals’ herbage intake during the month in units of MJ ME kg-1 DM. Area-specific data can be fed into the model.
- Mature cow weight: average liveweight for breeding females can be specified.
- Number of stock and classes: the total number of stock per class and their average starting liveweight.

6.2.5 MLA input data

Data were fed into the MLA calculator for the different farmer wealth categories, as these have varying numbers of livestock (Chapter 4). The better-off farmers had 14 cattle on average, while the average and the poor households had 6 and 2 cattle, respectively. Feed demand was only estimated for cattle. The grazing area was calculated using the current stocking rate 0.3 TLU ha^{-1} (ICRISAT, survey 2008). Calculations for feed demand were done for 12 months from January to December. Pasture growth rate was simulated using APSIM and ME values obtained from literature (Table 6.2); Cattle classes were defined and starting liveweight measured (Table 6.3).

Table 6.2 Monthly pasture growth rates and quality expressed as metabolisable energy content of animals' herbage intake.

Month	Pasture growth * (kg DM $ha^{-1}day^{-1}$)	Pasture quality* (MJ ME kg^{-1} DM)
January	17.46	9.73
February	13.92	9.73
March	7.58	9.73
April	1.32	8.12
May	0.01	8.12
June	0.00	8.12
July	0.00	7.18
August	0.00	6.50
September	0.01	6.50
October	0.31	8.12
November	1.68	9.73
December	9.40	9.73
mean	**2.54**	**8.45**

* Data sources: daily grass growth rates; APSIM version 6.1, Pasture quality MJ ME kg^{-1}; Day et al. (1999), Simbaya (2000), Snijders et al. (2008).

Table 6.3 Cattle classes and starting liveweight for the three farmer wealth categories.

Class	Number of stock	Starting weight
	Better-off	
Above 3 years	8	354
1 to 2 years	4	260
Weaned calves	2	150
	Average	
Above 3 years	3	332
1 to 2 years	2	277
Weaned calves	1	189
	Poor	
Above 3 years	1	189
1 to 2 years	**1**	**332**
Weaned calves	--	--

6.3 Results

6.3.1 Livestock herd size and composition

The most common farm animals in smallholder farming systems in Nkayi district are cattle, goats, donkeys and sheep. Livestock numbers and types vary across farmer wealth categories (Table 6.4). The better-off farmers own the highest numbers of all livestock types. Cattle are more predominant than other livestock types among the better-off and the average wealth categories. Average cattle ownership is 14, 6 and 2 cattle for better-off, average and poor farmers, respectively. Breeding female cattle constitute about 40% of the herd size across all wealth categories. The second largest group is that of male intact followed by calves and young females in the better-off and average farmer categories.

Table 6.4 Average livestock numbers per household and wealth category in Nkayi District, September 2008

Livestock	Better-off	Average	Poor
Breeding females	5.4	2.3	0.8
Male intact	3.1	1.2	0.4
Young females	2.6	0.7	0.1
Male castrated	1.1	0.4	0.1
Calves	2.3	1.1	0.1
Goats	7.7	3.9	1.7
Donkeys	2.8	0.9	0.8
Sheep	**0.8**	**0.2**	--

6.3.2 Dry-season feed shortages

Livestock largely depend on natural pasture for feed with adjuncts such as crop residues and locally available tree pods during the dry season. During the rainy season, animals have enough feed from natural pasture but as the season progresses, feed quantity and quality reduce substantially (Figure 6.3 a-c). Farmers in all wealth categories indicated that feed shortages occur mainly during the dry season starting from August to November. Peak months for feed shortages are September and October. A greater number of respondents in the better-off and average categories indicated feed shortages for cattle than for goats.

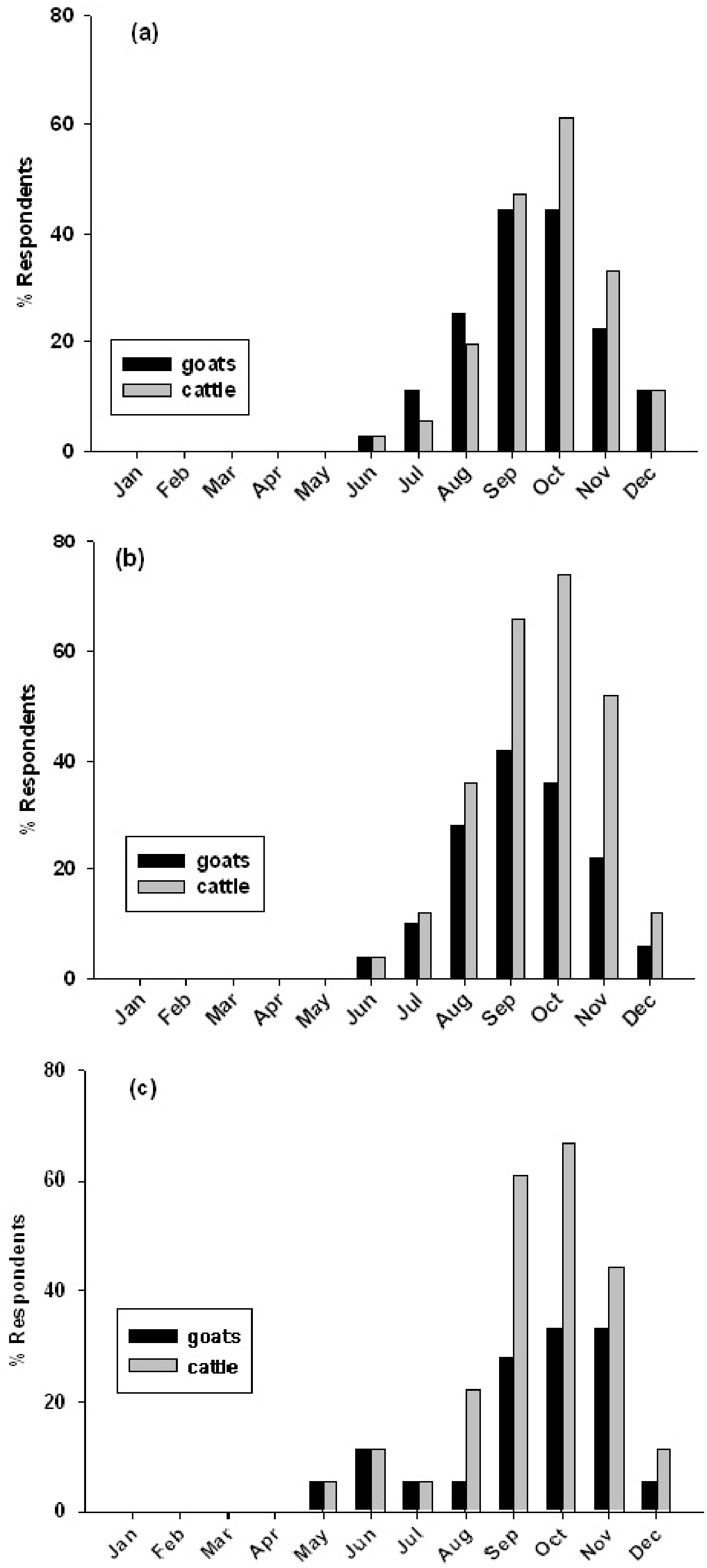

Figure 6.3 a-c Periods of feed shortages for cattle and goats in Nkayi district as indicated by farmers from three farmer wealth categories; (a) poor, (b) average and (c) better-off.

6.3.3 Dry-season feed management strategies

Farmers use a variety of feed and fodder sources to alleviate dry-season feed shortages. Some of these adjuncts are crop residues, locally available tree pods, cultivated forages and home mixes, which include salt and crushed cereal grain (Figure 6.4 a-b). The most common feed adjuncts are crop residues for both cattle and goats across all wealth categories. About 39%, 34% and 50% of respondents among the poor, average and better-off farmers, respectively, indicated that they use crop residues to alleviate goat feed shortages during the dry season, whilst about 47%, 76% and 72% of respondents among the poor, average and better-off farmers, respectively, indicated that they use these to alleviate cattle feed shortages. Locally available pods from different trees are the second most common feed supplement for both cattle and goats across all farmer wealth categories. To a lesser extent, farmers also use home mixes and cultivated forages as feed supplements. These alternative feeding strategies are mainly used for livestock survival and better body condition. A substantially higher number of farmers among the average and better-off categories use alternative strategies to alleviate cattle than goat feed shortages.

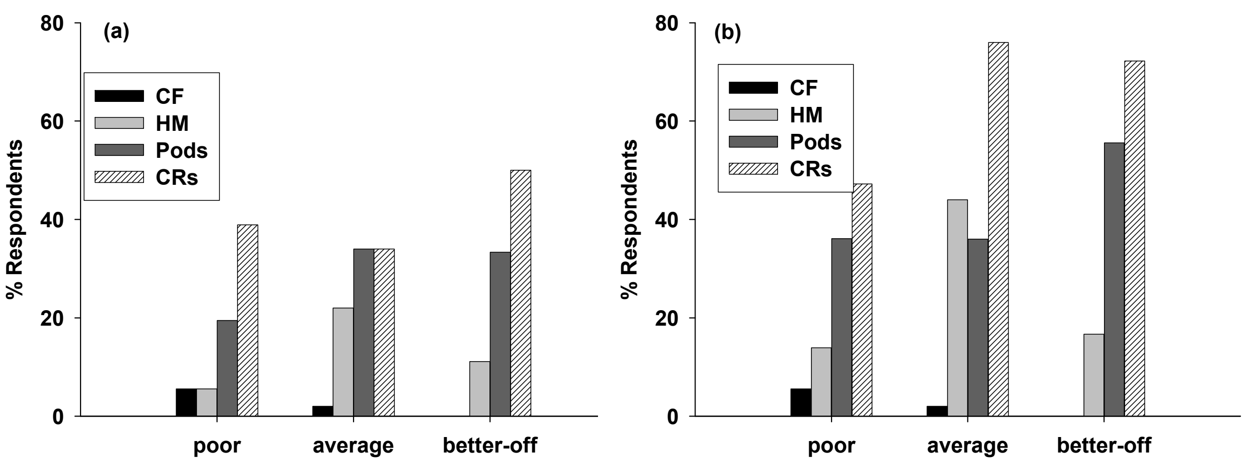

Figure 6.4 a-b Alternative feed strategies during dry season for (a) goats and (b) cattle across farmer wealth categories. CF= cultivated forages; HM= home mixes (salt, crushed cereal grain); Pods= locally available tree pods; CRs= crop residues.

6.3.4 Use of crop residues

Crop residues are the most common feed source for alleviating feed shortages during the dry season, i.e., from maize, groundnuts, cowpeas and sorghum (Figure 6.5 a-b). Across all wealth categories, maize residues are the most commonly used followed by groundnut for both cattle and goats. Amongst farmers who use crop residues as dry feed, about 82% of from the poor category use maize residues for goats compared to 56% and 25% in the average and better-off categories, respectively. The variety of crop residue use is more pronounced among the better-off category as compared to the other two wealth groups. About 25% of respondents from the better-off category use maize residues as goat dry season feed supplement, while about 30% and 25% of respondents in the same category use groundnut and cowpea residues, respectively,. About 55% of the respondents from the better-off category use maize residues for cattle compared to 68% and 80% in the average and poor categories, respectively.

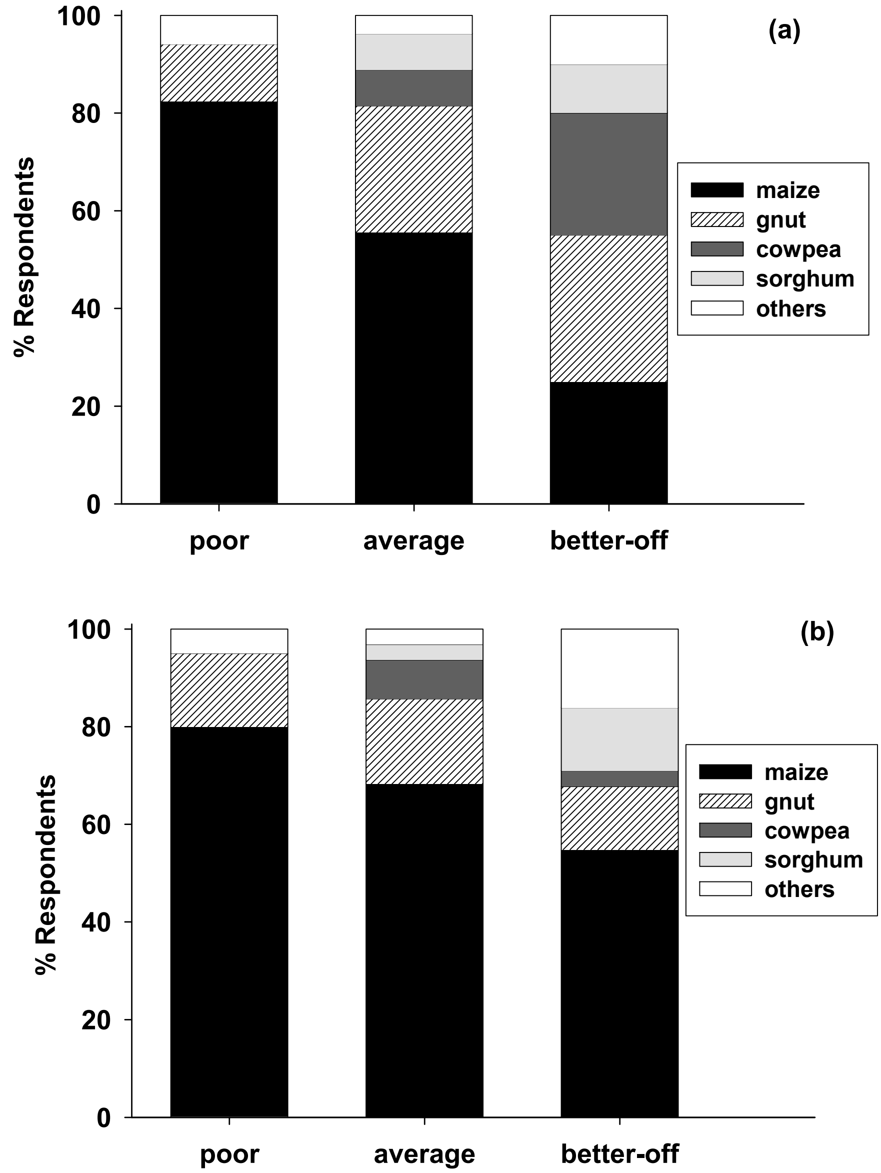

Figure 6.5 a-b Crop residues used by farmers to alleviate feed shortages during the dry season for (a) goats and (b) cattle. Others= sugar beans, millet, sunflower

6.3.5 Milk production

Farmers mostly milk their cows from November until May, although some can extend further into the dry season. Average milk production was 1.3 l cow^{-1} day^{-1} across farmer categories, but production varied over the one-year study period and across the farmer categories (Figure 6.6). Highest milk yields of 1.8 and 2.1 l cow^{-1} day^{-1} were recorded in February and March for the better-off and average farmer categories, respectively. The lowest milk yields of 0.25 l cow^{-1} day^{-1} were recorded in August and September for the average category. For the better-off category, lowest milk yields of 0.67 l cow^{-1} day^{-1} were recorded in June. The average monthly milk yield over the study period was 38 l cow^{-1} month^{-1} among the wealth categories. Milk yield was higher during the wet season than during the dry season across all farmer categories.

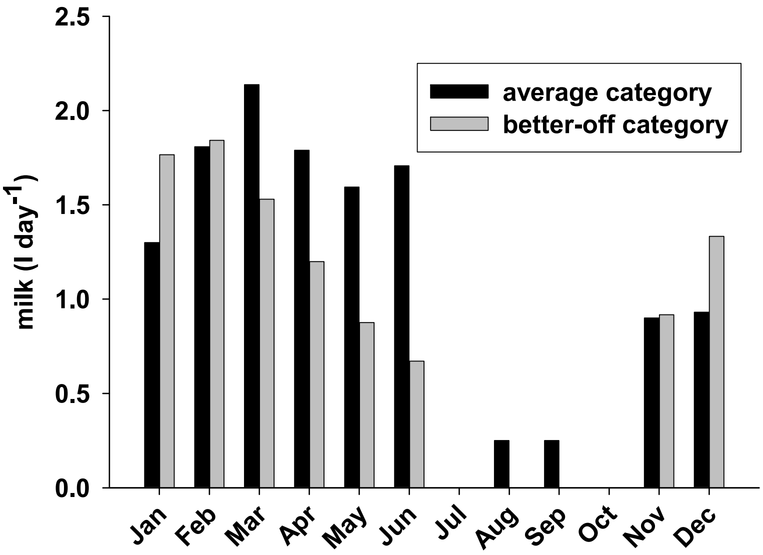

Figure 6.6 Daily milk production of cows measured for the farmer wealth categories: better-off (number of cows = 20) and average (number of cows = 9)

6.3.6 Cattle daily liveweight gains

Cattle liveweight gains varied across age groups among the wealth categories (Table 6.5). Calves within the age 1-2 months had highest gains across all cattle age groups, although there were no significant differences ($p<0.1$). Live-weight gains of 0.20 and 0.22 kg day^{-1} were recorded for calves less than 1 year old for the average and better-off farmer categories, respectively. Calves over 1 year on average gained 0.12 kg day^{-1} in both farmer categories. On average, liveweight gains reduced as number of years increased, with negative values (0.02 kg weight loss per day) recorded for cattle over 5 years old for the average farmer category. For the better-off category, liveweight gain for cattle over 5 years was 0.02 kg day^{-1}. There were significant differences ($p<0.1$) between liveweight gain of the young animals (0 to 4 years) and the older animals (over 5 years). On average, young animals liveweight gain was 0.15 and 0.13 kg day^{-1} while for the older animals it was -0.02 and 0.02 kg day^{-1} for the average and better-off farmer categories, respectively.

Table 6.5 Average daily liveweight gain (standard error in brackets) of different cattle age groups across farmer categories in Nkayi District

	Average	n	Better-off	n
Calves <1 year	0.20 (0.06)	5	0.22 (0.04)	10
Calves >1 year	0.12 (0.05)	13	0.12 (0.07)	15
3 to 4 years	0.15 (0.12)	15	0.11 (0.05)	16
Over 5 years	-0.02 (0.09)	19	0.02 (0.05)	43
	Mean liveweight gain for young and old cattle			
Young (0-4 years)	0.15 (0.06)	33	0.13 (0.04)	41
Old (over 5 years)	-0.02 (0.09)	19	0.02 (0.05)	43

6.3.7 Seasonal liveweight dynamics

Liveweight gains and losses varied across the one-year study period for different cattle types (Figure 6.7 a-b). Cattle in both the better-off and average wealth category show variability in monthly liveweight gains. Generally, cattle started gaining weight from November to February followed by weight losses in March and April. From May to June liveweight increased followed by another decrease in July. Liveweight losses were higher in March to May in the average category as compared to the better-off category. Average weight losses in this period were 40 and 20 kg $month^{-1}$ in the average and better-off farmer categories, respectively. High losses of 40 kg $month^{-1}$ were recorded for cows in March and bulls in May for the average category. For the better-off category, the highest losses of 20 kg $month^{-1}$ were recorded for cows in April. Live-weight losses experienced from July to September were almost similar across farmer categories. Highest losses recorded were 10 kg $month^{-1}$. Losses recorded for oxen were higher than for bulls and cows during the same period. Higher losses were recorded during the wet season than during the dry season across all wealth categories.

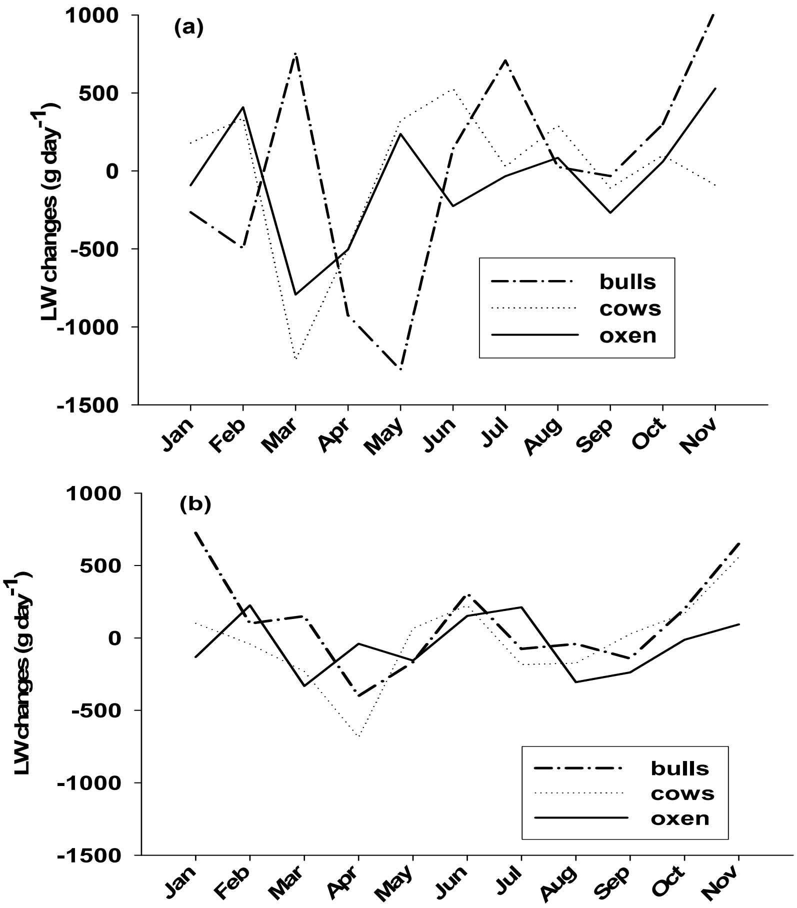

Figure 6.7 a-b Measured average daily liveweight of different cattle types for (a) average (number of bulls = 8; cows = 26; oxen = 7) and (b) better-off (number of bulls = 6; cows = 33; oxen = 27) farmer wealth categories, in Nkayi District.

6.3.8 Livestock feed demand and supply

Data from the MLA feed demand calculator show that all farmers in the three wealth categories experience feed shortages from August to October in an average year when grass production is 1.6 t ha $^{-1}$ and stocking rate 0.3 TLU ha^{-1} (Figure 6.8 a-c). Substantial grass growth occurs only in 6 months from November to April. Livestock get their feed from freshly grown biomass during the wet season and from carry-over pasture during the rest of the year. Feed demand is influenced by the number of livestock owned by the different farmer categories. The better-off farmers had the highest feed deficit of 7 ton for the three months of feed shortage while the average and the poor farmer categories had 3 and 1 ton feed deficit, respectively. On average, the feed deficit was approximately 500 kg per animal during the period of feed shortages.

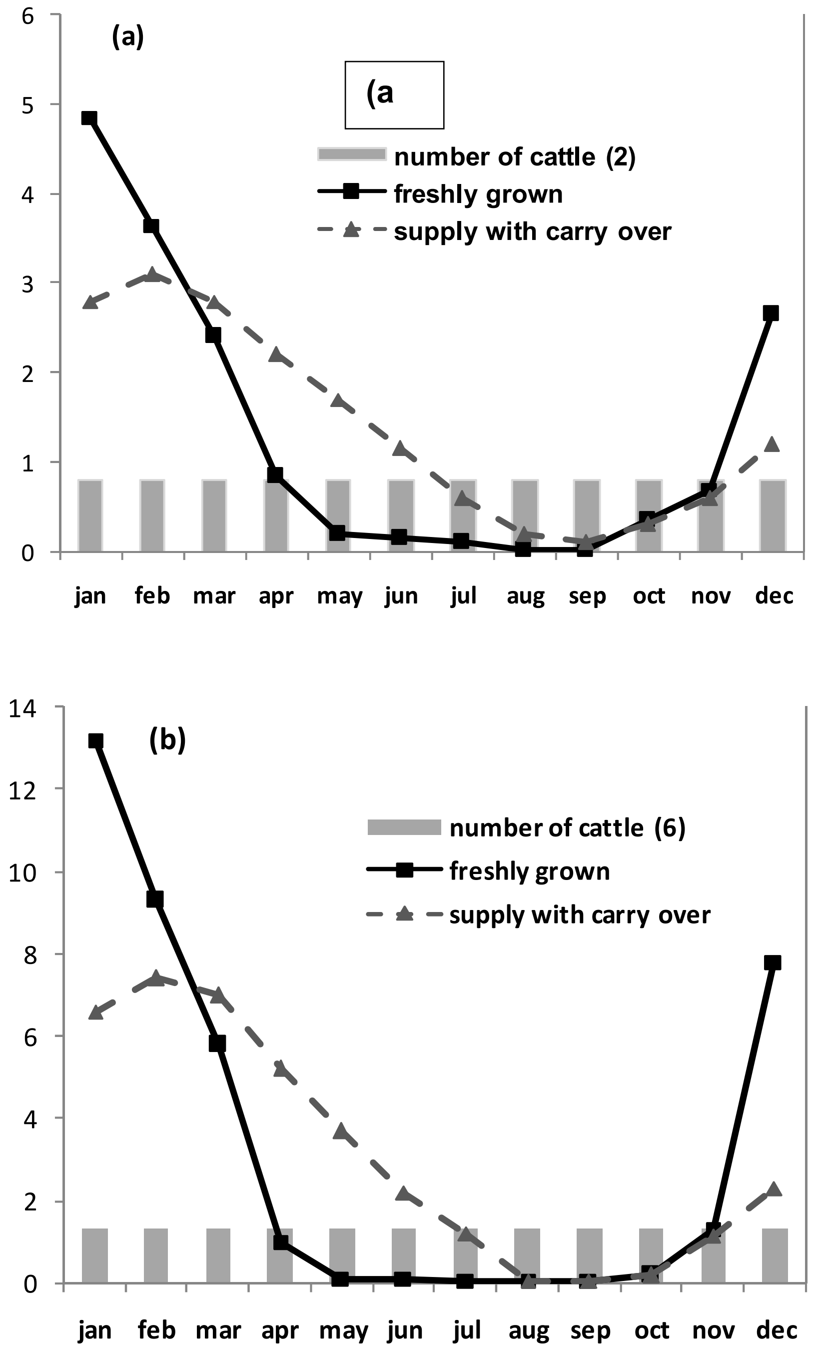

Figure 6.8 a-c Simulated feed demand for the different cattle numbers compared to the supply of pasture for (a) poor, (b) average and (c) better-off farmer categories. Bars show the total amount of pasture dry matter demand by all livestock per month; solid and dotted lines represents freshly grown pasture and supply with carryover, respectively.

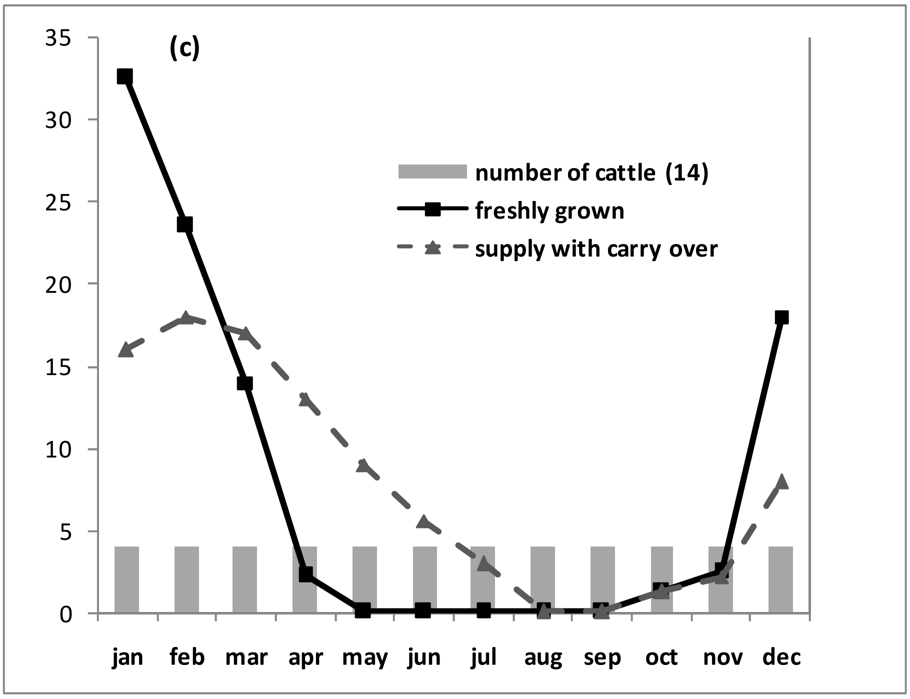

Figure 6.8 a-c continued

6.3.9 Potential feed supply of maize stover and mucuna biomass

The potential of maize stover and mucuna biomass produced under the conventional farmer practice (FP), manure (MN) and maize-mucuna rotation (MMR) as dry-season feed supplement was evaluated across the three wealth categories. Average maize stover production ranged from 1.5 t ha^{-1} to 1.9 under the FP and MN treatments across all wealth categories, while average total maize stover and mucuna biomass yield under MMR treatment was 6.9, 7.8 and 7.2 t ha^{-1} for the poor, average and better-off farmer categories, respectively. Results show that feed demand during the dry season can be met to varying degrees using the biomass produced under the different treatments (Figure 6.9 a-c). Maize stover produced under FP and MN treatments met 100% daily dry matter intake (DMI) requirements during the dry season at a probability of exceedance of 100% for the poor farmers. Maize stover produced under the FP and MN treatment in the average farmer category can only supply 100% of DMI required at a probability of 40 and 55%, respectively while stover under the same treatments by the better-off cannot. Biomass produced under MMR treatment, which includes maize stover and mucuna, can meet 100% of DMI required at a probability of exceedance of 100%, 100% and 50% for the poor, average and better-off farmer categories, respectively. About 50% can be met at a probability of exceedance of more than 96% under the MMR treatment for the better-off category

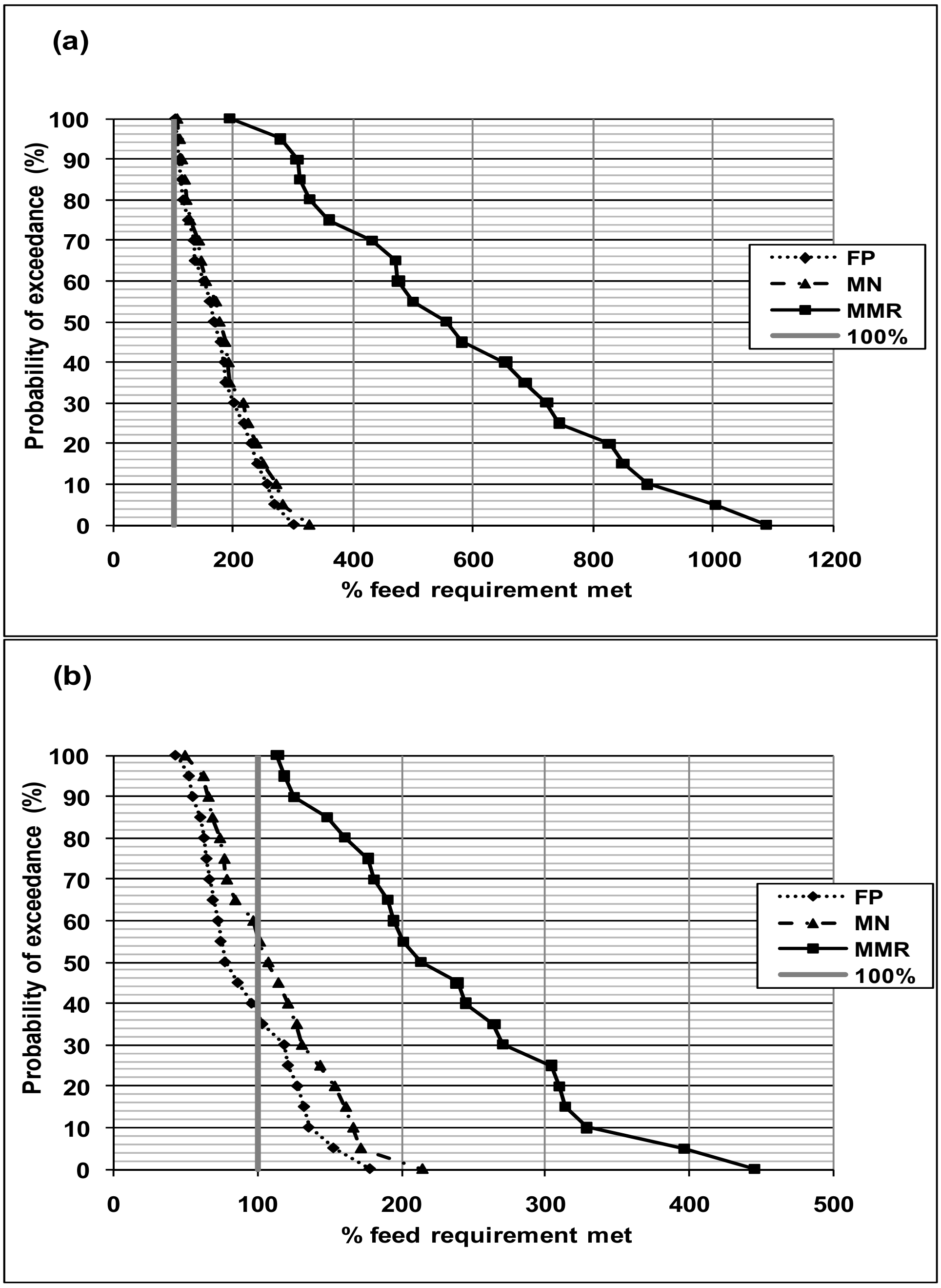

Figure 6.9 a-c Probability of exceeding daily DMI required during the dry season under three fertility treatments and farmer wealth categories (a) poor (b) average and (c) better-off. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation.

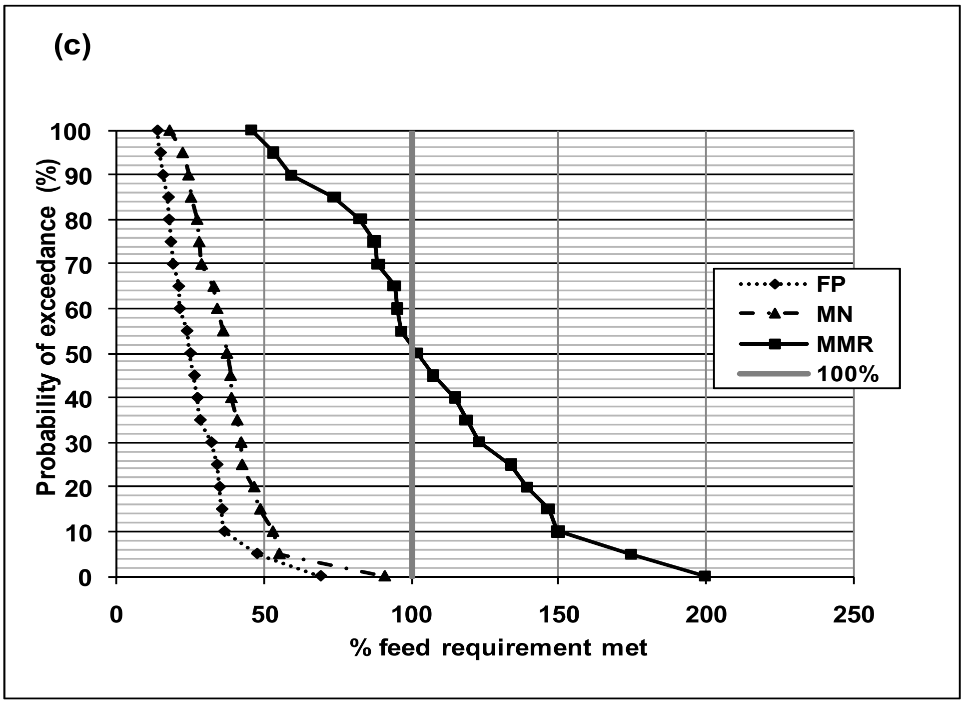

Figure 6.9 a-c continued

6.3.10 Maize stover crude protein content

The three fertility treatments had different effects on maize stover N content in the three farmer categories (Figure 6.10). Maize stover grown under the FP and MN treatments had the lowest crude protein (CP) content across all wealth categories. Average CP under FP was about 30 g kg^{-1} across all farmer categories. The MN treatment had only a minimal effect on stover CP in the poor farmer category but a slightly stronger effect for the average and better-off farmer categories of 3 and 5 g kg^{-1}, respectively, as compared to the CP under the FP treatment. The rotation treatment had substantial effects on maize stover CP content across all farmer categories. Stover CP under MMR was 87, 90 and 70 g kg^{-1} for the poor, average and better-off farmers, respectively. The CP content in mucuna biomass surpassed that of maize stover across all treatments. Average CP in mucuna biomass was 173, 175 and 175 g kg^{-1} for the poor, average and better-off farmer categories, respectively.

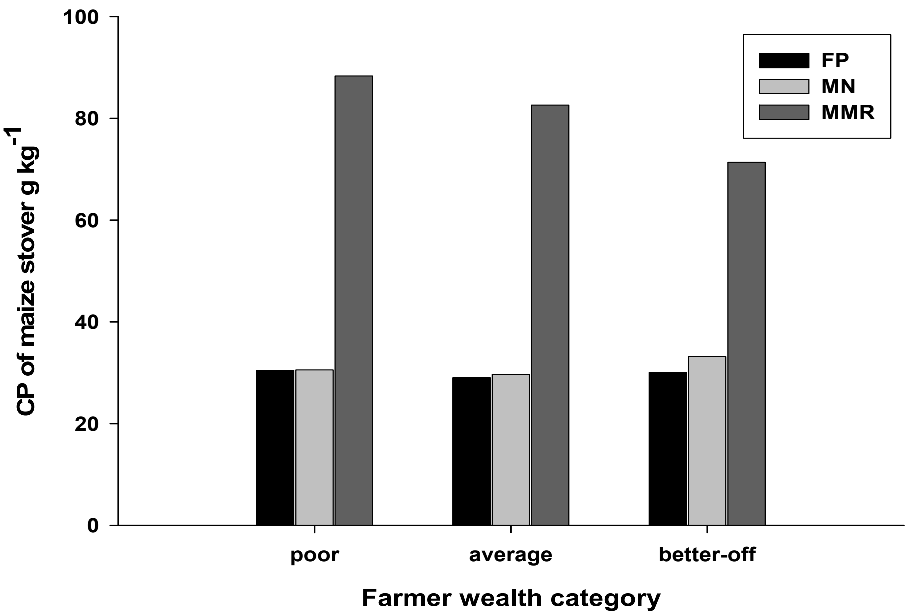

Figure 6.9 Crude protein content of maize stover under three fertility treatments and farmer wealth categories. FP = farmer practice, MN = manure, MMR = maize-mucuna rotation.

6.4 Discussion and conclusions

6.4.1 Feed shortages and management strategies

Farmers reported that there are seasonal feed fluctuations in terms of feed quantity. During the rainy season, there are substantial amounts of feed, but quantities decrease as the year progresses. Shortages were said to be more prevalent from September to November with October being the peak months. It was stated that feed shortages are more pronounced for cattle than for goats. This can be attributed to the fact that goats are better browsers than cattle and probably the farmers' higher preference for cattle than for goats, especially by farmers in the average and better-off categories. The farmers are also aware of feed quality, as they indicated that sometimes during the dry season although there might be plenty of grass, it is not palatable and animals lose weight despite availability. Seasonal feed variations have been reported in research work done on smallholder farms in Zimbabwe (Illius et al. 2003; Ngongoni et al. 2006; Mapiye et al. 2009). The variations are related to the fact that pasture production is directly linked to environmental conditions such as rainfall, and also that during the rainy season, crude protein content ranges between 120-160 g CP kg^{-1} and declines to as low as 10-20 g CP kg^{-1} dry matter in the dry season (Baloyi et al.1997; Maasdorp and Titterton 1997; Mpairwe 2005).

Farmers have different strategies to alleviate dry-season feed shortages, including use of crop residues, naturally available pods, home mixes (salt, crushed grain) and cultivated forages. In the smallholder mixed crop-livestock systems of Nkayi District, crop residues are the predominant sources of dry-season feed. Among the crop residues, maize stover is widely used, as it is the most common cereal crop in the area, followed by locally available pods. Common coarse salt (NaCl) is also used to improve palatability of crop residues and livestock appetite. There seems to be a general agreement that Na is deficient in most tropical grasses, which can be corrected by providing common salt *ad libitum,* which also satisfies the requirement for chloride (McDowell 1985a). While salt might increase feed intake, it also makes the animals thirsty, thus causing an increase in the amount of necessary drinking water. This might have negative effects, as there are water shortages during the dry season and animals have to walk long distances to access water. Farmers use alternative feeding strategies during the dry season mainly for animal survival and better body condition. Other alternative technologies such as cultivated forages, urea-treated stover and purchased commercial feeds were not commonly used in the area. This is attributed to lack of knowledge, unavailability, and high purchasing prizes (Ngongoni et al. 2006).

6.4.2 Milk production

In Nkayi District farmers milk their cows for about 8 to 10 months with an average daily milk production of 1.3 l cow^{-1} day^{-1}. Milk yields varied across farmer wealth categories. The better-off farmers milked their cows from November to June, while the average farmers milked their cows from November to September. Milk yields were highest during the wet season from December to April for the better-off farmers, while high yields extended up to June for the average category. These higher milk yields can be attributed to abundant feed during the wet season. In May and June, the high milk yields can be attributed to increased grazing land as animals start to graze on crop fields during this period. Total milk production in the average and better-off farmer categories was 238 and 237 l cow^{-1} during the 8 and 10 months of milking, respectively. This can be attributed to the fact that farmers do not milk their cows completely as they leave some milk for the calf. Farmers also reported that most of their cows have 1 or 2 teats, which are not functional due to damages by ticks. Low milk yields have been attributed to a number of factors such as breed type, animal health, feed quantity and quality, and socio-economic factors among others. Kebreab et al (2005) highlighted that in most communal areas, dairying cannot be viewed in isolation from other farm activities, the most important of which is producing the staple food of the household. In the developing world, 82% of total draft power comes from livestock and in the past decades the number of cattle and buffaloes used for multiple production purposes, including draft power, has increased by 23% (FAO 1992b). Thus, there is an indication that the higher energy demand of work, lactation and reproduction are not met given the poor feeding systems (Kebreab et al. 2005). The reported lactation period for indigenous cows in the smallholder farming systems of Zimbabwe is about 201 days (Ngongoni et al. 2006). In the current study, average milk production was about 261 l per lactation period, and more than 600 l have been reported for cows in smallholder farming systems of Zimbabwe (Mpofu 2006; Ngongoni et al. 2006). Potential milk production of indigenous cows ranges from 5 to 12 l day^{-1} under good husbandry (Mpofu 2006; Ngongoni et al. 2006). There is scope to increase milk production in Nkayi district through improved health, feed and management systems.

6.4.3 Liveweight dynamics

Cattle showed a regular pattern of liveweight changes consisting of gains of about 10-15 kg month^{-1} from November to February followed by losses of 20-40 kg month^{-1} from March to May. Weight gains can be attributed to feed availability in terms of quantity and quality. However, the effects are short lived, as there were massive losses from March to May. This can be attributed to poor kraal conditions and tick-related diseases. A study in Zimbabwe by Norval (1990) reported liveweight losses of cattle of about 4 g day^{-1} per female engorged with *Rhipicephalus appendiculatus* and about 10 g day^{-1} with *Amblyomma herbarium*. The study also shows that these losses can amount to 20 kg lost liveweight in steers over 3.5 months (Norval 1990). In many areas, maximum growth and tick burden occur at the same time (hot wet season), so the opportunity for compensatory growth is not always available unless supplementation is provided and health is good (Norval 1988; Kabreab et al. 2005). Ticks can be controlled with acaricides most commonly applied by dipping or spraying. Disease control services are normally provided by the Government Department of Veterinary Services, but due to economic hardships these services were not available to farmers during the study period. For economic reasons, farmers use methods such as hand picking and chickens to pick ticks from their livestock. These methods are not very effective when infestations are high. Effective and convenient methods would be the use of acaricide sprays, hand dressing and injectible compounds. Use of these methods can also be constrained in communal farmer systems due to unavailability and high purchasing prizes. In the current study, higher losses were recorded in the average farmer category than in the better-off. This can be attributed to the ability of the better-off farmers to purchase acaricides for tick control as compared to the other group.

Another liveweight loss phase was recorded in the dry season from July to September. Average weight losses recorded during this period ranged from 3 to 10 kg month^{-1}. They were not as high as those recorded during the wet season. This can be attributed to feed shortages during the dry season. Weight losses during the dry season were within the feed shortage period indicated by the farmers across all wealth categories. Although weight losses during this period were not as high as those during the wet season, feed shortages should always be avoided as they impose a double constraint on animal production. Feed shortage periods not only reduce the rate of forage intake, but also it is biologically inefficient for animals to lose weight and regain it later (Kebreab et al. 2005; Moore et al. 2009). Part of this inefficiency is that an animal requires more energy through a cycle of weight gain followed by weight loss and recovery compared with the same net weight gain followed by maintenance (Moore et al. 2009). If farmers could maintain liveweight gained during the period from May to June, then when the rainy season starts they could benefit from services such as draft power (for timely planting), increased milk production and better resistance to diseases during the wet season. This study shows that management practices for better cattle productivity should be employed both during the wet and dry season to minimize stresses from poor kraal conditions, diseases and feed shortages.

Measured daily liveweight gain varied across animal age groups. Within the group of calves that were less than 1 year old, daily liveweight gain was 0.21 kg day^{-1}. The rate of growth seemed to decrease with age, as daily liveweight gain for animals over 1 year old was 0.12 kg day^{-1}. Liveweight of animals over 5 years old fluctuated over the 1 year study period, but on average there were net weight losses ranging from 0.01-0.05 g day^{-1} across all farmer categories. When cattle reach mature adult weight, their liveweight generally remains constant with temporary gains and losses depending on factors such as feed supply and quality among others (Snijders et al. 2008). In smallholder farming systems, although older animal do not gain weight, there is no reason for culling or selling as the animal will still be capable of proving services such as draft power (Barret 1991; Kabreab et al. 2005). Besides draft power, these old animals also provide financial security and serve socio-cultural functions (Barret 1991).

6.4.4 Potential contribution of maize stover and mucuna biomass

Simulation models assist in evaluating promising options for changes in livestock, crop, soil and water management in different production systems (Cavero et al. 2000; Yang et al. 2006). The MLA feed demand calculator was used to evaluate the potential feed deficits for livestock being fed under natural pasture across three farmer wealth categories. Feed deficits from August to October were 7, 3 and 1 tons under the better-off, average and poor farmer categories, respectively. In current livestock production systems, farmers do not use purchased feed supplements nor do they grow forage crops. Dry-season feed deficits are partially covered by untreated crop residues from grain cereals and legumes. To address one of the major constraints in livestock production, the potential production of maize stover and mucuna biomass was evaluated using a simulation approach. Maize stover and mucuna were evaluated mainly for their prospective contributory effects to dry-season livestock feed in smallholder farming systems. Crop residues play a vital role in supplementing livestock feed during the three months of critical feed shortages. Maize stover currently produced under conventional farming practices does not suffice in terms of quantity and quality of total dry matter required. Use of alternative cropping systems such as maize-mucuna rotation can substantially improve both the quantity and quality of the stover and hence the degree of sufficiency. Simulation results show that maize stover under FP and MN treatments can only supply about 100%, 50% and 13 % of cattle dry matter requirements in the poor, average and better-off farmer categories, respectively. Crude protein (CP) content in maize stover under FP and MN treatment can only supply about 13% of the daily required CP, considering that CP required for body maintenance of 300 kg liveweight is 228 g day^{-1}. The maize stover under FP and MN falls short of both the required quantity and quality across all wealth categories. Under the MMR treatment maize stover quality was substantially increased by more than 2-fold for the better-off and average, and by over 3-fold in the poor farmer categories. In terms of dry matter requirements, 100% of cattle needs can be met by biomass produced under the MMR treatment at 100, 96 and 50% probability in the poor, average and better-off farmer categories, respectively. In terms of CP requirements, 100% of cattle feed needs can be met across all wealth categories by crop biomass from the MMR treatment.

Technologies that need external inputs have had low adoption by farmers mainly due to unavailability of inputs on the local markets and high purchasing prices. The quality of cereal crop residues can be enhanced through crop management options that are low in cost and use locally available inputs such as cultivated forage legumes. Growing maize in rotation with mucuna can substantially increase maize grain, and the quantity and quality of livestock feed. Poor soil fertility and inadequate feed supplies are the major constraints in the mixed crop-livestock systems that are typical of smallholder farming systems. Integrating forage legumes in current cropping systems is one promising technology, which can be used to improve crop production, soil fertility and livestock production. Land availability can hinder inclusion of cultivated forage legumes in smallholder farming systems. In the current study, average cropland holding per household was 4 ha and about 1 ha of total owned cropland was under weedy fallows. Research has also shown that in Zimbabwe most smallholder farmers use barely 50% of their total cropland (Rohrbach and Alumira 2002). One major reason given by farmers for weed fallowing was soil fertility restoration (Maasdorp et al. 2004). Forage legumes such as mucuna can be grown on fallow land to improve soil fertility and livestock feed requirements. Improving livestock water productivity through increased use of crop residues could be detrimental to soil conservation if all or even most residues are removed from the fields to feed the livestock (Blümmel et al. 2009). Simulation results (Chapter 5) show that the poor and average farmers can turn in about 3.1 and 2.3 t ha^{-1} year^{-1} of crop residues, respectively. This might be detrimental to the better-off farmers as they use almost all their crop residues due to high livestock numbers, however, they can benefit from manure application of about 4.5 t ha^{-1}.

In smallholder farming systems of Zimbabwe, mucuna has been selected as one of the most favorable forage legumes in intercropping and ley experiments (Maasdorp et al. 2004), mainly because of its large seeds, easy adaptation, high biomass production and as it increases yields of subsequent cereal crops (Nyambati 2002; Maasdorp et al. 2004). In this study observed on-farm mucuna yields ranged from 2.2 to 4.8 t ha^{-1} (Chapter 4). A combination of energy-providing crops such as maize and protein-rich crops such as herbaceous legumes can produce protein-rich silage adequate for livestock maintenance and production (Maasdorp and Titterton 1997).

6.4.5 Implications for livestock water productivity

At an average current growth rate of 0.16 kg day^{-1}, a calf will need about 5 years to attain mature cow weight, which is about 300 kg in the study area. Livestock water productivity, as a function of products and services obtained from livestock over the amount of water consumed (through feed), will be low in situations of low animal productivity. The animal will take longer to mature and consequently it will consume more to attain a productive stage where it can reproduce, produce milk or be used for draft power. If farmers can maintain the growth rate of about 0.25 kg day^{-1} exhibited by one-year-old calves, their animals have the potential to reach a liveweight of 300 kg in about 3 years. Growth rates of about 0.27 have been recorded for cattle under natural pasture in Zimbabwe (Voster 1964). Feeds are of the critical factor in livestock husbandry, since adequate feed supply largely determines livestock productivity while the way feed is produced affects sustainable natural resource use in terms of land and water (Blümmel et al. 2009).

Simulated cattle feed deficits by the MLA model during the dry season were approximately 5.5 kg DM per animal per day. The potential of maize stover and mucuna biomass to meet these feed deficits varied across treatments and farmer wealth categories across the 30 simulated years. Energy (ME) and crude protein (CP) required for body maintenance of 300 kg live weight cow is 34.6 MJ day^{-1} and 228 g CP day^{-1}, respectively, while ME and CP for production per kg of milk with a fat content of 3.6% is 5.0 MJ and 81 g CP. Maize stover and mucuna biomass from the MMR treatment have the potential to supply the above-mentioned nutrient requirements across all farmer wealth categories (Table 6.6). Water used to produce daily available DM ranged from 1.2 to 6.9 m^3 across treatments and farmer categories. The highest water was consumed under the FP and MN treatments while the lowest was in stover produced under the MMR treatment. According to Peden et al (2007), water consumed in feed by 1 TLU can amount up to 5 m^3 per day. In the current study the amount of water needed to produce daily dry matter under the MMR treatment for a 300kg cow with potential milk production of 1 l day^{-1} was about 3.4 m^3 across all farmer wealth categories.

Feed produced under the MMR treatment can substantially increase LWP, as the same amount of water is used to produce both food and feed. The feed has the potential to maintain cattle weight, and this is important for draft power at the beginning of the cropping season. Growing supplementary feed on-farm has positive effects on the environment by reducing land degradation through minimized animal movements in search of feed on depleted grazing land. Stall feeding helps to save energy through reduced walking distances during the dry season, and saved energy can be converted into beneficial outputs such as milk, weight gain and or maintenance. Crop residues are some of the few feed resources that can be produced without additional input of land and water and are therefore inherently resource efficient feed sources (Blümmel et al. 2009). The quality of crop residues can be improved through inclusion of forage legumes in current cropping systems.

Livestock water productivity is defined as the ratio of livestock products and services to the amount of water used in producing these products and services (Peden et al. 2007). In the current study, results show that substantial livestock benefits are obtained mainly from manure in the form of N, P and K fertilizer, followed by draft power and milk. These three important animal products strongly depend on feed quality and quantity. Improving feed resources during the dry season, for example, can be beneficial to livestock, as more than 70% of calving occurs during this period (Ngongoni et al. 2006). Improving feed can build up disease resistance and increase milk production, and also improves animal body condition. Livestock water productivity in the study area is only 0.04 US\$ m^{-3}; this is attributed to low livestock productivity especially due to feed shortages, poor animal health and management conditions. If farmers can improve animal health conditions and management (especially kraal conditions) during the wet season and improve feed quality and quantity during the dry season, LWP can be increased.

Although improved feed can substantially increase LWP, efforts can be hampered by other problems such as poor health systems, husbandry and water shortages during the dry season. For example, the mortality rate in the study area ranged from 12 to 29%. With such high rates, all efforts to improve LWP will be undermined as the animal that dies takes with it all the water it would have utilized directly and indirectly during its lifespan (Amede et al. 2009). Information on the effect of seasonal changes on herd dynamics and management in communal areas is scarce, making it difficult to assess the efficiency of utilization of communal rangelands (Mapiye et al. 2009). There is a need for further work to better understand and quantify the potential effects of these factors on livestock water productivity in smallholder farming systems in Nkayi District. It is also important to note that livestock innovation is a social process; it is not possible to achieve LWP improvements unless close attention is paid to policies, institutions and the associated processes (Amede et al. 2009).

Table 6.6 Potential contribution of maize stover and mucuna biomass to daily dry matter intake (DMI), crude protein (CP) and metabolisable energy (ME) requirements for body maintenance of 300 kg live weight and amount of water used to produce maize stover and mucuna biomass under different treatments across the three farmer wealth categories. FP = farmer practice, MD = micro-dose, MMR_mz = maize stover from the maize-mucuna rotation, MMR_muc= mucuna biomass from the maize-mucuna rotation.

Farmer wealth category	Treatment	Available feed (kg)	Available energy ME/day (MJ)	Available protein CP/day (kg)	WP (kg m^{-3})	Water used to produce daily available dry matter (m^3)
Poor	**FP**	5.5	40.7	167.6	0.8	6.9
	MN	5.5	40.7	168.0	0.8	6.6
	MMR_mz	2.8	20.4	242.9	2.3	1.2
	MMR_muc	2.8	20.4	479.7	1.2	2.2
Average	**FP**	5.1	38.0	149.0	0.9	5.6
	MN	5.5	40.7	163.3	1.1	4.9
	MMR_mz	2.8	20.4	227.1	2.4	1.2
	MMR_muc	2.8	20.4	480.0	1.2	2.3
Better-off	**FP**	1.5	10.3	45.7	1.0	1.5
	MN	2.1	15.8	70.6	1.5	1.4
	MMR_mz	2.8	20.4	196.3	2.3	1.2
	MMR_muc	2.8	20.4	479.3	1.2	2.2

7 CONCLUDING REMARKS

The main determinants of wealth in smallholder farming systems in Nkayi district are livestock (mainly cattle) numbers and level of crop (mainly maize) production. Crop and livestock production are the main livelihood activities for subsistence and cash income. Farmers do not benefit fully from these activities as there are a number of associated constraints. The major constraints for livestock production are diseases, feed shortages and drinking water during the dry season, and for crop production poor soil fertility and labor shortages. Farmers also stated that crop and livestock markets are not well developed in the area. This leads to formation of informal markets, which were said to be poorly coordinated and put farmers at a disadvantage as they cannot negotiate for better prices. Crop and livestock production is also influenced by policy and institutional factors that act at individual farm, local community and country level. Social and commercial services are available, but most were poorly equipped and therefore offer limited services to farmers. Constraints with solutions within the farmers' capabilities were evaluated using field experiments and a modeling approach. The two major constraints addressed were poor soil fertility and feed shortages during the dry season.

Technologies selected were those that use locally available low-cost inputs such as manure and crop residues (maize and forage legumes). The APSIM model was used to evaluate the potential effects of three crop production technologies, namely FP, MN and MMR for improving soil fertility, WP_{grain} and livestock feed. These technologies were evaluated for three farmer wealth categories (poor, average and better-off). Of the three technologies, simulations show that the MMR treatment had the highest potential to improve both crop and livestock productivity in the smallholder farming systems in Nkayi district. The MMR treatment substantially increased maize grain yield, WP_{grain}, SOC and TN across all farmer wealth categories. To determine the robustness of this technology, potential N and SW stress was also simulated under years of worst, normal and best rainfall conditions. The MMR treatment performed very well when water was not limiting in the system. Nitrate-nitrogen ranged from 50 to 200 kg ha^{-1} yr^{-1}, hence no N stress was simulated. Crop residues from this treatment could supply 100% of daily requirements of a 300 kg liveweight animal in terms of DM, CP and ME requirements. Improved feed can increase total on-farm productivity directly by increasing milk production, manure quality and indirectly by improving crop productivity. Increased crop production will enhance supplementary feed especially during the dry season. This will also enhance crop-livestock interactions which are currently not very strong in the study area.

Results of the simulations also show that, the MMR treatment satisfies six out of the seven criteria used for selecting best-bet technologies that can be implemented under smallholder farming systems, (Mercuria and Waddington 2002):

1. Short-term benefits: maize grain and livestock feed were improved in the first year of technology application under normal rainfall conditions
2. Long-term benefits: positive effects on soil fertility i.e. SOC and TN were substantially increased for the poor and average farmers while they were maintained for the better-off farmers.
3. Little competition for arable land: mucuna can be grown on fallow land; in this study average fallow land was 1 ha per household.
4. Benefits were simulated for all farmer wealth categories
5. Compatibility with other components of the farming system: the technology enhances crop-livestock interactions
6. Potential to raise crop and livestock productivity, hence generation of on-farm income.

The criteria that was not evaluated was labor demand for technology implementation under smallholder farming conditions. This could limit adoption by farmers, but if benefits such as increased income from crop and livestock production are realized, there are high chances that farmers will be willing to adopt the technology.

The MMR treatment can be used as an alternative technology that can improve total on-farm productivity in mixed crop-livestock systems, and hence poverty reduction. For example, average number of people per household in the study area was 9, and each person requires about 120 kg of grain per year[4]. Total grain required per household would be about 1100 kg yr^{-1}; average maize grain production under the MMR treatment was 2200 kg ha^{-1}. On average a household can thus have about 1000 kg yr^{-1} of surplus

[4] Maize intake g/person/day = 330.9 (FAO, 1992)

grain. This can be sold or stored in silos for later use, especially when a drought year is forecasted. Cash obtained from grain sales can be used to buy vaccines to improve livestock health and hence improve productivity. In this scenario, maize will serve as both food and cash income, and hence has the potential to reduce poverty and hunger in smallholder farming systems.

The simulation results also show that LWP can be increased during the dry season, when crop residues from the MMR treatment are fed to livestock. This is possible because high crop production can be achieved using the same amount of water. Potential benefits i.e. increased milk production, manure quality, draft power and resistance to diseases, can be achieved as a result of improved nutrition. However, these benefits are short-lived as they only apply to 3 months in a year. In the other 9 months, farmers can only improve LWP by increasing output, as they cannot improve pasture water productivity now or even in the near future, because the grazing areas are communal. In Nkayi district, livestock output (products and services) can be increased by:

4. Reducing livestock mortality rate: In the study area, average mortality rates were 17 and 28% for cattle and goats, respectively. If these losses can be converted into beneficial products, LWP can be substantially increased.
5. Improving livestock management practices especially those influencing animal health and kraal conditions during the wet season
6. Focusing on market-oriented development (Dar et al. 2010): Farmers keep cattle mainly for draft power followed by milk, security, manure and to a lesser extent cash income. As opposed to cattle, goats are primarily kept for meat and cash income, thus improving goat production under these systems can be used as an entry point for reorientation from subsistence to commercial farming. Making the leap from subsistence farming to commercially oriented livestock production has been a development objective in the region for a long time, but has had very little success (Homann et al. 2007).

It is important to note that crop and livestock innovations are a social process; it is therefore not possible to gain productivity improvements unless close attention is paid to policies, institutions and their associated processes (Amede et al. 2009). There is also a need for policies and institutions that can provide incentives for smallholder farmers aiming at food security and commercialization. While improved production and marketing can help many smallholder farmers to escape the poverty trap, the farmers also need to produce the right product and to have access to information and appropriate support services (Homann et al. 2007).

7.1 Further research

Simulation models assist in evaluating promising options for changes in livestock, crop, and soil and water management in different production systems. The simulated strategies need to be tested under smallholder farming systems in the semi-arid areas, and also to extrapolate the results to other climatic conditions in Zimbabwe.

The study mainly focused on the potential contribution of maize stover and mucuna biomass to daily feed requirements in terms of DM, CP and ME. Further work needs to be done to test the potential of crop residues as adjuncts to dry-season feed combined with good health and management conditions on overall livestock productivity (milk production, manure quality, liveweight gain).

Labor demand was not evaluated. Harvesting mucuna for hay is done at flowering to ensure good quality. This is approximately 90 days after sowing, which can be between February and April depending on sowing period (sowing window November to December). Labor demand and supply could be an issue during that time. It will be important to assess labor demand for technology implementation and also to look at alternative solutions such as the use of simple animal-drawn hay making equipment, which can be used to alleviate labor shortages.

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