Decision-making for heterogeneity

Diversity in resources, farmers' objectives and livelihood strategies in northern Nigeria

2009

Tropical Resource Management Papers, No. 94 (2009); ISBN 978-90-8585-670-2

Also published as thesis (2009), Wageningen University: ISBN 978-90-8585-522-4

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Diversity in resources, farmers' objectives and livelihood strategies in northern Nigeria

Ezra D. Berkhout

…For my parents…

The research described in this thesis was financially supported by the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. A junior research grant was provided by Mansholt Graduate School of Social Sciences, Wageningen University, The Netherlands to enable completion of this thesis at Wageningen University during 2008/2009. Financial support from Wageningen University and IITA for printing this thesis is gratefully acknowledged.

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Topical Resource Management Papers, ISSN 0926 9495.

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Documents sur la Gestion des Ressources Tropicales, ISSN 0926-9495

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Introduction

1.1 Background

“Farmers in northern Katsina are well aware that the days of shifting cultivation have long since disappeared”, observed Luning (1963) in the early 1960s. For how long exactly is further illustrated by Watts (1983), who notes that population density in the early 18th century in the Kano emirate, neighbouring Katsina, must in some parts have been close to 115 inhabitants per square kilometre. By then, these areas were already characterized by continuous farming systems, without fallowing. Fallowing, or shifting cultivation, is a practice in which a field is not cultivated for some years to restore its fertility level naturally. Nevertheless, even with such high population densities, farmers were able to sustain production levels through the application of considerable amounts of manure, crop rotation and/or intercropping (Watts, 1983). Currently, these same techniques are advocated as the most important strategies to maintain indigenous soil fertility levels. Hence, the methods used by pre-colonial farmers to maintain soil fertility were not very different from the ones observed today.

In response to the diminishing possibilities of maintaining soil fertility through fallowing, smallholder farmers respond in different ways. Both on-farm and off-farm strategies to cope with reduced farm size, lower soil fertility and production levels, are well documented. On-farm strategies aimed at maintaining soil fertility levels include, amongst others, crop-livestock integration, crop rotation, increased use of inorganic fertilizer, and the creation of fertility hotspots, or their combination. Crop-livestock integration entails the feeding of crop residues to animals for the production and subsequent application of organic fertilizer, and this process is viewed as a first step in stepping up intensification as a result of population growth (McIntire *et al.*, 1992). Improved systems of crop rotation, whereby cereals are rotated with nitrogen-fixing legumes, could further provide high-quality feed for livestock (e.g., Sanginga *et al.*, 2003). Furthermore, farmers well integrated into markets opt to increase the use of inorganic fertilizer, whereby in some cases inorganic fertilizer completely replaces the use of organic manure (Abdoulaye and Lowenberg-DeBoer, 2000). Finally, farmers are known to maintain fertility ‘hotspots’ on their farm, either by intensive fertilization of a particular field, or by shifting the homestead after several years with the associated application of domestic waste, human and animal faeces (e.g., Gandah *et al*., 2003; Voortman *et al.*, 2004; Rowe *et al.*, 2006).

At the same time, many farmers can no longer solely rely on farming as their principal source of income due to reduced average farm size and diversify into off-farm income sources such as petty trading, food processing, local manufacturing jobs, or migrate (seasonally) to large urban areas in search of temporary jobs (e.g., Ellis, 2000). Hence, the coping strategies in the wake of increased population pressure are manifold, and the rural population in the savannah regions in West Africa, as in many other parts of Sub-Saharan Africa, is far from homogenous. In this thesis, three types of frequently unobserved heterogeneity are explored in further detail.

First, as argued, one farmer may differ from his/her neighbour in its livelihood strategy, as expressed through differences in crops grown, inputs used and engagement in off-farm activities. As will be shown such differences in strategies are likely to be a result of -largely unobserved- heterogeneity in goals and preferences, in addition to other, directly observable, differences in household characteristics. Second, differences in past cropping strategies and for example the maintenance of one or more fertility hotspots, has given rise to heterogeneity in land and farm. Third, livestock plays a crucial role in maintaining soil fertility levels, but also serves as an important insurance and wealth storage mechanism. The relative preferences for such non-productive roles of livestock may vary among households and relate to differences in livestock and other household assets.

Clearly, many of these types of observed and unobserved heterogeneity are related, but have so far received only limited attention in agricultural research. In conventional farm household modelling approaches, behavioural homogeneity is frequently assumed. Furthermore, applied productivity studies as a rule include basic household characteristics to capture farmer goals, though it is not clear whether such characteristics adequately capture heterogeneity in goals and objectives. Furthermore, agricultural productivity analyses of smallholder farms usually assume homogenous field quality, an assumption ill-conditioned in view of a large body of research describing within-field soil fertility differences (e.g., De Ridder *et al.*, 2004; Titonell *et al.*, 2008).

The aim of the research presented in this thesis is to examine in more detail the consequences of ignoring these types of heterogeneity. It is analysed how such heterogeneity can better explain observed farmer behaviour, and how such insights can assist researchers and policy-makers in promoting the sustainable use of soil resources.

The remainder of this chapter is organised as follows. First, in Section 1.2 an overview is given of how agricultural research addresses soil fertility replenishment in the savannah regions. At the same time, it is argued how and why the above-mentioned types of heterogeneity are important. Based on this discussion, the main research questions are further elaborated in Section 1.3 and the structure of this study is presented in further detail. In Section 1.4, an overview is given of the various data sources used throughout this document. Finally, in Section 1.5 the major methods of analysis deployed in this thesis are discussed.

1.2 Population growth, intensification and agricultural research

Luning (1963) made his observation on the near absence of fallowing in Katsina State, Northern Nigeria, based on an agro-ecological survey carried out for FAO in 1960. This survey was, coincidentally, partly done in the same locations analysed in this study. Table 1.1 provides a comparison of key characteristics observed both in the FAO survey in 1960 and the surveys used in this thesis. In the 1960s, keeping fields fallow was almost non-existent in one location (Bindawa), while it was already at very low levels in other locations. In Mashi, fallow accounted for 12 to 22 percent of total farm size.

The data in Table 1.1 illustrate the steady population growth in Bindawa and around Mashi over the past decades, as in many other areas in the savannah regions in West Africa. In both locations population density doubled. As expected this increase in population has led to a considerable reduction in per capita farmland in around Mashi district, from 0.86 ha in 1960 to 0.28 in 2007.

Rather surprisingly, actual farm size per capita has not declined in all areas over the past 45 years. In Bindawa, for example, the most heavily populated area at the time of the survey in 1960, actual farm size per capita increased. While this could largely be attributable to measurement errors in field size, it may also suggest that marginal lands and communal grazing lands have been brought under continuous cultivation since then.

The growth in population, and the consequent reduction in available arable land per capita, has widespread implications for food production in the West African savannah regions. Most importantly, with natural regeneration methods to maintain soil fertility such as fallowing no longer feasible, crop yields are likely to drop.

Table 1.1: Comparison of historical average characteristics of villages in Katsina, Nigeria.

Area[1]	Year[2]	Population density[3] (# km^{-2})	Household size (#)	Farm size (ha)	Farm size per capita (ha)	Fallow[4] (%)	Cereal yield[5] (kg ha^{-1})	Groundnut yield[5] (kg ha^{-1})
Bindawa	1960	119	6.50	2.44	0.38	2 - 3	588	420
	2007	210 - 250	8.05	3.66	0.45	0	546	487
Mashi / Kaita	1960	66	7.00	6.00	0.86	12 - 22	354	253
	2007	140 - 170	5.21	1.47	0.28	0	536	280

[1] Denotes the official Local Government Area (LGA) in which the survey was carried out. The data for Bindawa were however collected in neighbouring hamlets within the same LGA. Mashi and Kaita are neighbouring LGA's in the extreme north of Katsina state (see also Figure 1.1);

[2] All figures for 1960 are based on the data provided by Luning (1963); all figures for 2007 are based on the data collected for this thesis (see also Section 1.3);

[3] Population density in 2007 is based on data from the IITA GIS-Lab (pers. comm.);

[4] Fallow is expressed as the percentage of fields left fallow of the total farm size surveyed;

[5] Yield figures of 2007 reflect total production obtained from a typical intercropped millet-groundnut field of 1 hectare. Luning (1963) provides average yield data in the region for pure stands. Without further information on the exact nature of intercropping practices, the assumption is made that cereals and groundnut each cover 50% of a hectare.

The data on crop yields provided by Luning (1960), in addition to the villages presented in Table 1.1, suggest average cereal grain yields in the region of around 500-600 kg/ha, while (unshelled) groundnut yields approximate 400-500 kg/ha. In the surveys carried out in this research, crop yields in an intercropped system with millet and groundnut are largely similar in Bindawa. Similarly, the crop yields observed in Kaita, in the research presented in this thesis, are slightly higher than the ones observed in 1960 in nearby Mashi. At first sight, these figures do not seem to suggest a drop in yields over time. However, they cannot be compared realistically without accounting for a multitude of additional factors such as input use.

In fact, many researchers suggest that crop yields have been steadily decreasing over time (e.g., Watts, 1983), but there is little historical on-farm production data to sustain these claims. In a comprehensive socio-economic and historical study in northern Nigeria, Watts (1983) stresses that yield estimates in the colonial era, and shortly thereafter, are prone to large measurement errors, while both temporal and spatial fluctuations in weather greatly influence differences between observations. Similarly, Luning (1963) expressed serious concern about the reliability of his field size and yield estimates, while the measurements of field sizes in the current research are also likely to suffer from such errors (see also Section 1.4).

Given the difficulties in identifying yield decline in an on-farm setting, most of the current evidence on declining yields comes from field trials at research stations. Vanlauwe *et al.* (2005) describe a long-term field trial implemented by the International Institute of Tropical Agriculture (IITA) in southwestern Nigeria, and discuss how maize yields drop considerably in 16-year continuous cultivation. Nziguheba *et al.* (2009), also describing this trial and other long-term trials in Nigeria and Benin, illustrate how this decline is attributable to depletion of macronutrients such as nitrogen (N) and phosphorus (P), but increasingly as well to depletion of micronutrients such as magnesium (Mg). This could be the result of an increased use of inorganic fertilizers, that contain macro- but not micronutrients, accelarating the depletion of the total stock of micronutrients.

As becomes clear, many farmers are facing a deteriorating agricultural production environment, and given the large share of Africa’s population that depends on agriculture, this has a severe impact on poverty levels. Hence, in the wake of rising food and fuel prices in 2008, the key role of agriculture in Africa’s development has gained new momentum (e.g., World Bank, 2008). Given the large share of smallholders employed in agriculture, increasing productivity is expected to be a strong driver of economic growth and/or poverty reduction, an argument that is sustained by empirical evidence (Christiaensen *et al.*, 2006).

To support the design of effective policies and technologies to revert soil fertility decline, scientists from both social and biophysical sciences jointly developed so-called bio-economic models. Such simulation models are mostly used for *ex ante* impact analysis, and are combinations of mathematical programming based farm household models (e.g., Hazell and Norton, 1986) and models from biophysical sciences describing soil fertility dynamics and plant growth. These models have been used for different purposes in various African settings including the savannah regions of West Africa (e.g., Sissoko, 1998; Kruseman, 2000).

The general consensus from many of these studies is that technology improvements alone cannot revert soil fertility decline, but that site-specific modifications of institutions, policies and technologies are required (e.g., Ruben *et al.*, 2001). Effective policies include both policies aimed at reducing (input) market imperfections, as well as policies aimed at promoting individual property rights of land. The latter policy type is said to explain much of the recent regeneration of soils in Niger (World Bank, 2008, Ch.8).

Many of the studies applying bio-economic models make use of the concept of nutrient budgets. In these studies, either a farm household production simulation model is combined with nutrient budgets, or nutrient budgets are calculated based on observed input and output quantities. Many of these studies show that simulated or observed nutrient budgets are negative, and soil fertility levels are expected to decline over time (e.g., De Ridder *et al.*, 2004).

Nevertheless, the use of such models is subject to criticism. First, as argued by De Ridder *et al.* (2004), many of the models assume farm land quality to be homogenous, while a number of studies (e.g., Gandah *et al.*, 2003; Rowe *et al.*, 2006; Titonell, 2007) show considerable within-farm or within-plot heterogeneity. These differences usually are the result of selective application of organic and/or inorganic fertilizer by farmers to specific plots, i.e., those where the marginal productivity of application is highest. As a result, the simulated nutrient budgets are on-farm averages and may not be very accurate when compared to actual farmer strategies. On the other hand, such models still offer the possibility to explore the effect of new technologies and policies, in particular the (direction of their) effect on soil nutrient budgets. Hence, even though simulated budgets at plot-level may not hold in detail, the researcher may still learn whether a specific policy or technology induces a farmer to use soils more sustainably.

A more important concern, however, is the rough or inaccurate representation of farmer behaviour. The linear-programming models, which commonly are at the base of such bio-economic models, are known to be sensitive to the specification of the criterion function. If there exists considerable heterogeneity in the objectives and goals that farmers pursue, this should be accurately accounted for in the criterion function. Otherwise the outcomes of the simulation models are likely to be inaccurate. Therefore, in Chapters 2 and 3 we map heterogeneity in goals and objectives, and demonstrate how this affects production decisions as well as nutrient budgets.

At the same time, a number of studies have set to determine gaps between actual output levels and potential output levels, i.e., inefficiencies, by applying both parametric (Stochastic Frontier Analysis) and non-parametric (Data Envelopment

Analysis) methods. The motivation of such studies is that the identification of the determinants of inefficiency can be used to develop policies to abate them, thereby increasing farm outputs without increasing inputs directly. For example, Alene and Manyong (2006) show how inefficieny can be explained from differential access to extension methods. Okike *et al*. (2001) identify determinants that lead farmers to integrate crops and livestock to a higher degree. They also show that manure significantly improves economic efficiency, without further unbundling the relationship between supply of manure and livestock ownership.

But, as mentioned before, the presence of within-field soil fertility differences is well documented and such differences are likely to explain a considerable part of the variation in production. The most common approach to account for such heterogeneity in efficiency studies is to include a variable reflecting perceived (by the farmer or researcher) levels of soil fertility (e.g., Barrett *et al.*, 2008). But even such a correction is applied in surprisingly few studies. In fact, it may not be unlikely that part of the levels of inefficiency can be attributed to such heterogeneity in soil fertility directly.

Similar to the concern raised on the validity of bio-economic simulation models, farmers' production decisions are a direct result of their individual goals and preferences. Hence, differences in market orientation, risk aversion and environmental concerns may largely explain differences in efficiency levels. Although a few studies document such differences among farms in European agriculture (e.g., Ondersteijn *et al.*, 2003), it is not known whether heterogeneity in goals and objectives plays a large role in smallholder agriculture in Africa.

Both the omission of information on soil fertility and farmer goals and objectives may induce omitted-variable bias in such efficiency estimations. Consequently, the parameters estimated, including the levels of efficiency, are likely to be biased. Both these aspects are further analysed in Chapters 2 and 4.

Finally, much of the current agricultural research focuses on improving the soil fertility base by improving the processes of crop-livestock integration. A main component of this integration is the feeding of livestock with crop residues, both low-quality cereal straws and high-quality legume residues. The resulting manure can then be applied to the arable land of the farm. As the results of Okike *et al*. (2001) suggest, application of manure significantly improves levels of farmer efficiency. In fact, as mentioned in Section 1.1, it is likely that crop-livestock integration already occurred in the densely populated areas around Kano in pre-colonial times, and mixed farming has played an important role for a long time. To improve the efficiency of the crop-livestock integrated system, the colonial governments in West Africa introduced bullocks into the local farming systems, whose draught power improved production efficiency (Sumberg, 1998). Moreover, when these bullocks were kept in confined spaces, this would also concentrate manure production. For these purposes the colonial administrators in northern Nigeria gave bullocks on loan to medium-sized farmers since 1928 (Luning, 1963).

Ever since, agricultural research has focused on further improving the efficiency at which nutrients are being recycled in such mixed or integrated systems. Plant breeders have set aims to develop high-yielding dual-purpose crop varieties, for example cowpea, providing both good grain and fodder yields (e.g., Singh *et al.*, 2003). Soil scientists have focused on further unravelling the relationships between crop yields and the various components making up ‘soil fertility’, as well as on the development of no-till farming systems. (Systems) agronomists have aimed at identifying more efficient combinations of cereals and legumes in intercropped systems (e.g., Singh and Ajeigbe, 2002), keeping in mind the dietary needs of both human and animal populations.

As implicitly recognized by the colonial administration, which only distributed bullocks to the wealthier households, mixed farming is not likely to be an efficient practice for all household types. Some recent empirical quantitative studies have set out to identify factors leading farmers to integrate crops and livestock to different degrees (Okike *et al.*, 2001, Manyong *et al.*, 2007), but these have so far not been very conclusive. Furthermore, the effectiveness of crop-livestock integration does not seem to be constant across different types of farms. Rufino (2008) shows that nutrient losses in manure production are largest amongst the poorest groups of farm households. Although technical interventions could reduce these losses, the poorest are not likely to be able to make the necessary investments.

Furthermore, the main objectives of keeping livestock, and their relative importance, may differ across households. As introduced in Bosman et *al.* (1997), and later applied by Moll (2005), households derive utility from keeping livestock through both tangible and non-tangible benefits. The first category includes components such as dairy, meat and manure production. The second category includes components related to variables that measure insurance, status and financing benefits derived from keeping livestock. In the absence of formal financial services, these non-tangible benefits may play a relatively important role.

So far, no study has analysed how these non-tangible benefits affect observed levels of crop-livestock integration. Such an analysis is carried out in Chapter 5, and also sheds light on the reasons for the low adoption rates of many interventions aimed at improving the nutritional status and productivity of livestock (e.g., Sumberg, 2002).

1.3 Research aims

The aim of this thesis is to examine in detail three types of heterogeneity discussed above, i.e., heterogeneity in goals and objectives, heterogeneity in soil fertility, and heterogeneity in crop-livestock integration. Heterogeneity is thereby analysed in relation to differences in household characteristics and farming strategies for the three types distinguished.

First, bio-economic models assume farmers to be homogenous in goals and preferences in their underlying utility function, while there is no clear reason for such an argument to hold. Rather surprisingly, heterogeneity in farmers' goals and strategies has received only limited attention in the use of bio-economic models. Similarly it has not received frequent attention in the analyses of smallholder productivity.

Second, most studies focusing on productivity and efficiency in agricultural production assume farms to be homogenous with respect to its soil qualities, an assumption refuted by numerous field studies (e.g., Titonell, 2008).

Third, livestock clearly plays an important role for production of manure, but this production is not the only reason for households to keep livestock. In fact, several other benefits, such as insurance, play a role. The relative importance of different goals for keeping livestock may vary among households, giving rise to differences in the degree to which a farmer integrates crops and livestock.

The implication of accounting for, or ignoring, the heterogeneity in goals and preferences of farmers is the subject of research in Chapters 2 and 3 of this thesis, albeit from different angles. In Chapter 2, differences in smallholder goals and preferences are analysed in a context of efficiency measures. First, such goals and preferences are quantified and related to household characteristics. Subsequently it is analysed whether such information gives a better explanation of observed differences in smallholder efficiency. Differences are then compared, using an analysis in which household characteristics are assumed to fully describe farmers' goals and preferences.

In Chapter 3, a different method is used to identify differences in farmer goals and preferences from observed production data, using Multi-Attribute Utility Theory (MAUT). Based on this method, we directly include the identified goals and preferences in a bio-economic model, and analyse how they affect efficient levels of soil fertility mining and replenishment through inspecting soil nutrient balances.

The effects of not accounting for soil fertility differences in a productivity study are explored in more detail in Chapter 4. While there is considerable evidence of between-plot heterogeneity in soil fertility levels, the costs of carrying out a detailed soil analysis at multiple plots and farms for a detailed productivity study are generally prohibitive. Therefore, a number of proxies, based on farm-level survey data, to capture such differences in soil fertility are proposed and tested in Chapter 4. The implications of omitting such proxies for efficiency and productivity estimations are analysed and compared for sorghum and maize.

In Chapter 5, a novel method to estimate (the impact of) differences in non-tangible benefits of keeping livestock is proposed and implemented. Clearly, differences in livestock holdings resulting from differences in non-tangible benefits will influence the level to which a farmer integrates crops and livestock. The analysis is seen in the light of emerging new cash crop practices in the savannah region, and further identifies which crops benefit from available manure.

Summarizing, the aims of the research presented in the five subsequent chapters in the remainder of this thesis are:

- Chapter 2: To quantify the degree to which smallholders differ in goals and objectives and such differences influence farm efficiency measures;
- Chapter 3: To determine the trade-offs between important production attributes farmers face; to quantify the degree to which farmers differ in heterogeneous production strategies, and to determine how such heterogeneity affects soil nutrient balances;

- Chapter 4: To identify how to account for heterogeneity in soil resources effectively and to determine how the inclusion of such information affects efficiency estimates for maize and sorghum;
- Chapter 5: To introduce a method to quantify non-tangible benefits of keeping livestock and to determine how differences in such benefits relate to differences in manure use and cropping patterns.

Chapter 6 discusses the results of the preceding chapters, the limitations of this study and also identifies further points of research. This discussion deals with three subjects. First the research in this study demonstrates the importance of including farmers' objectives in both an efficiency analysis and in applications of bio-economic models. In the efficiency analysis in Chapter 2, two variables, next to risk aversion, measuring farmers' goals and objectives influence production decisions. Moreover, production attributes such as risk aversion and sustainability differentially affect nutrient budgets. Furthermore, it is analysed how goals and objectives can be measured in more detail. Based on the observed sensitivity of farm household models to the specification of the criterion function, reflecting farmers' goals and objectives, recommendations are made to improve the accuracy of such simulation models. Finally, the implications for promoting and/or enhancing sustainable use of soil resources are discussed in detail. The results in this study suggest that the least-endowed farmers, characterized by high levels of risk aversion, do not enter the markets for high-value crops and use small amounts of inputs. It is discussed if and how policies and technologies can benefit this group of farmers, thereby increasing production and the sustainability of soil resource use.

1.4 Data collection and location

1.4.1 Surveys

The specific research aims and questions as outlined in the previous sections are addressed in the savannah regions of northern Nigeria, on the basis of four data sets. Table 1.2 provides a detailed overview of the exact contents of these data sets and where they were collected.

The choice of this region follows from the employment of the author at the International Institute of Tropical Agriculture (IITA) in Kano, northern Nigeria. In this position, one detailed socio-economic data set was readily available for analysis (Survey S1, Table 1.2). This initial socio-economic survey was subsequently complemented with a number of surveys carried out between 2004 and 2007.

Survey S1 was complemented with a detailed labour use data set S2, with the objective to quantify labour requirements for various crops. Both these data sets are used to calibrate the farm household model that is used in both Chapters 3 and 5 (see also Sub-Section 1.5.1). Also the data contained in S1 are used in the analysis presented in Chapter 4.

Additional data were collected throughout the cropping season of 2006 in 7 villages, comprising a total of 230 households, in the region of study. This data collection contains a detailed description of production practices (Survey S3) as well as an estimation of differences in farmers' goals and objectives for the same 230 households (Survey S4). Both data sets are used in the analyses in Chapters 2 and 5.

The advantages and limitations of the surveys to elicit goals and preferences, S4, are discussed in detail in Chapter 2. As discussed below, a number of potential sources of measurement errors were encountered during the implementation of the other surveys.

Table 1.2: Description of data sets used

Survey description	'Cash' - baseline survey	Labour use survey	Production data	Goals, objectives, beliefs and preferences
Survey code	S1	S2	S3	S4
Year of survey	2002	2005	2006	2006
Sample size	120 households	12 households; 87 plots	230 households; 951 plots	230 households
Villages in which data were collected	Ikuzeh; Hayin Dogo; Danayamaka	Ikuzeh; Hayin Dogo; Danayamaka	Ikuzeh; Hayin Dogo; Kiru; Warawa; Kunchi; Bindawa; Kaita	Ikuzeh; Hayin Dogo; Kiru; Warawa; Kunchi; Bindawa; Kaita
Type of data collected	Production data; household characteristics; asset and livestock holdings;	Labour input use; detailed field size measurements	Production data; household characteristics; asset and livestock holdings; detailed field measurements; access to loans	Fuzzy pairwise goal ranking; Likert-type questions

First, throughout this research, unless stated otherwise, we use estimates of field sizes as stated by the farmer. Nevertheless, these data could be prone to measurement errors, since actual measurement of all plots was not feasible for financial reasons. Furthermore, farmers appear not familiar with commonly used units of area such as hectares or acres. Farmers were therefore asked to express the size of fields owned in units of football fields, equal to one acre.

Subsequently, to obtain accurate information on labour use per unit of land, all 87 plots in S2 were measured with a measuring tape. Finally, a random sample of fields in S3 was measured with a handheld Global Positioning System (GPS). The measurement with a GPS is most accurate for larger plots, since the inaccuracy is relatively smaller. Comparison between these measurements and stated field sizes suggests that farmers are relatively well able to estimate the area of small plots (less than 1 hectare), but tend to overestimate the size of their larger plots.

In addition, in all locations data were collected on access to loans, and sizes of loans taken. Obtaining accurate information on financial aspects is notoriously difficult in rural areas in Sub-Saharan Africa (SSA), and in the surveys carried out for this research the situation was not different. These data have therefore not been used further due to their inherent unreliability.

Finally, data collection in northern Nigeria inevitably suffers from some degree of sexist bias (Watts, 1983). Access to rural married women was out of reach for a male researcher and his male assistants. Furthermore, only in Bindawa, households headed by women, more specifically widows, were encountered. While rural married women do own fields in some cases, they do not commonly cultivate these fields themselves. Therefore, in all calculations carried out, only fields, which are owned by the household head, have been taken into consideration

1.4.2 Locations

The choice of the villages initially was based on the availability of data in IITA-projects in Kaduna State, as mentioned above, in particular two projects, i.e., ‘Balanced Nutrient Management Systems’ (BNMS) and ‘Cereal and legume systems for higher farmer income, health and improved system sustainability’ (CASH). Baseline data collected for these projects in Kaduna State are used in this thesis. In addition, data were collected to obtain a better representation of the diversity in production practices across the region (Surveys S3 and S4).

The cultivation of cereal and legumes is dominant in the region, whereby drought-resistant millet is cultivated in the driest parts, while sorghum and maize are grown in those parts with higher levels and more stable patterns of rainfall. Traditionally, cereals are intercropped with groundnuts, the major export crop of Nigeria in the colonial era. While the large-scale export of groundnuts no longer exists, the domestic processing of groundnuts and subsequent sales by female household members, as well as the nutrient-rich groundnut-fodder for livestock, still makes it an important crop for many households. At the same time, cowpea and soybean are playing an increasingly important role in such intercropped systems.

Cowpea, or black-eyed pea, is a major food crop throughout West Africa. While cultivation mainly takes place in the savannah regions, consumption is significant throughout the coastal and equatorial forest regions. Due to its location, the grain market in Kano, in terms of volume the largest in Africa, plays a central role in cowpea trade between large producer areas such as Niger, Mali and northern Nigeria on one hand, and large concentrations of consumers in places such as southern Nigeria, Cameroon and Gabon on the other hand (IITA, 2004). Hence, while many farmers grow cowpea as a food crop, many also sell part of their production. Finally, soybean is mainly intercropped, but sometimes also sole cropped in the wetter savannah regions, mainly found in Kaduna State.

In addition to cereals and legumes, many other crops are cultivated in the region of study. Throughout this thesis we classify many of these crops as high-value crops. This category contains vegetables such as tomatoes, cabbage, pepper, garden egg, of which the mainstay of production is directly marketed.

Next to cereals, legumes and high-value crops, many farmers grow roots and tuber crops. First, cassava has traditionally been grown in the savannah regions, even in the driest parts. But also sweet potatoes and common, or Irish potatoes are widely cultivated. Again, much of the production of these crops is consumed in the household, but a substantial proportion is marketed as well.

Especially in riverbed or fadama fields, cultivation of sugarcane and rice is common, while rice cultivation also occurs at upland fields. Also many vegetables are cultivated in such fadamas. Finally, cotton production plays a role in some locations, though with the demise of the cotton-processing industry in Kaduna and Kano, only few farmers still cultivate this crop.

The exact combination of crops a farmer chooses depends on his preferences, his specific trade-offs, local soil fertility conditions and possibly varying degrees of non-tangible benefits in keeping livestock, which are all subject of research in this thesis. Naturally, crop choice also depends on the production potential in each location. Table 1.3 presents a detailed overview of the main agro-ecological characteristics of each location, in addition to the exact names of villages and Local Government Areas (LGA's).

Nigeria is a federal country, divided in 36 states, of which research for this study was carried out in three, i.e., Kaduna, Kano and Katsina. Population density in these states is amongst the highest in West Africa. The Nigerian population census in 2006 puts the total population in Kaduna, Kano and Katsina at 6.1, 9.3 and 5.8 million inhabitants, respectively and their population densities at 132, 466 and 239 inhabitants per km^2 respectively (NBS, 2009).

Each state is subdivided into Local Government Areas (LGA's), the lowest formal level of governance. The exact names of the villages and LGA's in which surveys are carried out are given in Table 1.3. In addition, Figure 1.1 provides an overview of the locations in which surveys were conducted, indicating their distance to markets and the agro-ecological zone in which they are located.

The first visits to the survey locations, in particular the locations in surveys S3 and S4, were made together with a representative of the Agricultural Development Program (ADP) of each state. The representative usually made contact with the local ADP-officer, housed in each of the LGA's. Together with these ADP-staff members a first visit to each village head was made to explain the purpose of the research in more detail. After the village head agreed to his cooperation in this research, an appointment was made with village elders to draw up a household list. Farm households were sampled randomly from the household list, by using the random number generator in Microsoft Excel. Each sampled household head was subsequently explained the purpose of the research and asked if he was willing to participate. All selected households agreed to this request.

Households were not paid in any kind for participating in this research. That said, two household heads died in the course of this research and both families received a bag of cowpea as a condolence gift. Both households were not further included in the analysis. Finally, at the end of the research, all households from Kano that participated in the research were invited to attend a field visit at the IITA research farm in Kano State.

Table 1.3: Main agro-ecological characteristics of the surveyed locations

Village name	*Local Government Area*	*State*	*Agro-ecological zone*[1]	*Length growing period*[2]	*Mean annual rainfall*[2]	*Soil classification*[3]	*Population density (# km^2)*[2]
Ikuzeh	Chikun	Kaduna	SGS / NGS	159	1230	Ferric Lixisols	
Hayin Dogo	Giwa	Kaduna	NGS	148	1081	Haplic Luvisols	140 -170
Danayamaka	Makarfi	Kaduna	NGS	149	1008	Haplic Lixisols	170 - 210
Ba'awa	Kiru	Kano	NGS / SS	140	921	Eutric Cambisols	170 - 210
Warawa	Warawa	Kano	SS	130	753	Haplic Arenosols	570 - 980
Sauta Janbuge	Kunchi	Kano	SS	102	669	Luvic arenols	120 - 140
Shibdawa	Bindawa	Katsina	SS	107	662	Luvic arenols	210 - 250
Babban Ruga	Kaita	Katsina	SS / Sahel	92	535	Luvic arenols	140 - 170

[1] Southern Guinea Savannah (SGS), Northern Guinea Savannah (NGS), Soudan Savannah (SS), Sahel Savannah
[2] IITA-GIS Laboratory (pers. comm.)
[3] IITA-GIS Laboratory (pers. comm.), based on the classification by Sonneveld (2005)

Furthermore, at various points throughout this research use is made of secondary data on historical crop yields, as well as rural and urban market prices since the late 1990s. These data are kindly provided by the regional agricultural development programs in Kaduna state (KADP), Kano State (KNARDA) and Katsina State (KTARDA). Finally, use is made of additional research findings provided by agronomical field research carried out by (former) IITA-scientists in this region for a large number of years (i.e., Vanlauwe *et al.*, 2001; Sanginga *et al.*, 2003; Nwoke *et al.*, 2004; Nziguheba *et al.*, 2009).

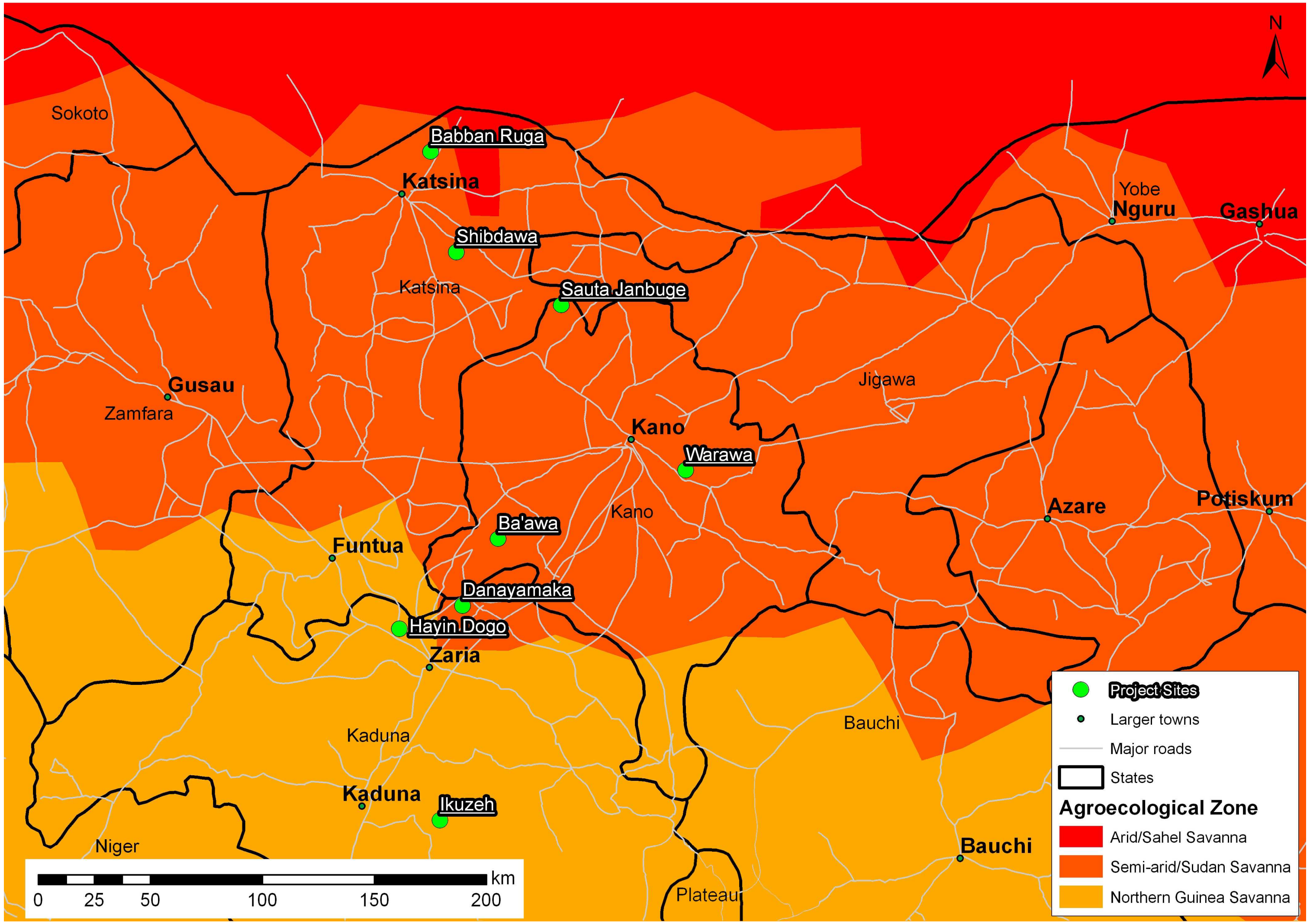

Figure 1.1: Locations of data collection

1.5 Methods of analysis

Different methods of quantitative analysis, both parametric and non-parametric are used in this thesis. In each chapter a justification for the use of each method, in relation to the specific research questions, is given. In this section, a brief overview of the major methods used is provided.

The analyses presented in Chapters 3 and 5 are based on farm household modelling. A basic overview of the functioning of such a model is provided in Sub-Section 1.5.1, while a full mathematical description, including a detailed description of the parameters and data sources, is provided in Appendix B.

Furthermore, in Chapters 2 and 4 estimates of farmer efficiency levels are used. In Sub-section 1.5.2 a description is given of how efficiency is estimated. At various points throughout this research use is made of regression analysis, the details of which are described in each chapter.

1.5.1 Farm household modelling

The developed bio-economic model is used in Chapter 3 to identify the effect of variations in farm household behaviour on soil nutrient balances. The same model is used in Chapter 5 to explore efficient levels of crop-livestock integration at different levels of land and labour availability, and varying degrees of non-tangible benefits of keeping livestock. In the latter chapter the model is extended with a module describing potential herd size and livestock weight changes, as described in more detail in Section 5.3.

Bio-economic models are an integration of classical farm household models (e.g., Schweigman, 1985; Hazell and Norton, 1986) and biophysical models from agronomy and soil science (e.g., van Keulen and Wolf, 1986). They are powerful tools for simulating farming in its complex environment, and for *ex ante* assessment of new technologies and policies, and have been applied in various regions for various purposes (see Heerink *et al.*, 2001 for a comprehensive overview). The rationale is to incorporate the level of soil nutrient mining or replenishment, for one or a few of the most important nutrients, based on the farm plan chosen, as an economic decision. Then, the yearly overall changes in soil nutrient stocks become decision variables in a programming-based farm household model, while changes in the soil nutrient stocks, dependent on policy and technology change, can be determined.

Many applications, including ours, include a balance equation, which adds the changes in soil nutrient stocks to a classic farm household model. Removed nutrients in crop products and applied nutrients in (in)organic fertilizer constitute the basis of the balance. In our analysis, we include deposited nutrients through wind and water, in addition to correcting for gaseous losses of applied inorganic fertilizers. This follows the procedure described by FAO (2004).

The household model determines efficient levels of input use, cropping patterns, and consumption and marketing decisions (e.g., Schweigman, 1985). The cropping patterns included in the household model are based on (combinations of) crops grown in the region of study.

We further assume imperfections in output markets, expressed in differences between farm gate and market prices, based on price differences obtained from regional governmental organizations. This price band reflects that farmers face transaction costs in the sales and/or purchases of agricultural commodities.

We include average monthly off-farm income in the model as a parameter, based on the data collected, as additional income that can be used either for purchasing inputs or consumption goods. Hence, for reasons of simplicity, we assume off-farm income to be exogenous. Furthermore, the monthly labour available for farming is based on the household composition, corrected for child and female labour.
The model follows a hierarchical optimisation structure, in which domestic food needs are included in the constraint set. We assume that farmers first strive to meet household necessities such as sufficient staple foods, additional food demands (e.g., meat, cooking oil, vegetables), and expenses such as clothing, education costs and medical care. To incorporate this decision structure, constraints are included to ensure that sufficient energy and proteins are produced and/or purchased to meet annual demands in the family (based on FAO, 2006). In addition, a separate constraint ensures that sufficient cash resources are available every month to meet other necessary expenses.

1.5.2 Efficiency analyses

In Chapter 2, a non-parametric method, i.e., Data Envelopment Analysis (DEA), is used to determine various efficiency levels. The choice to use DEA is made because of its flexibility to include multiple inputs and outputs, given the relatively large number of crops grown and inputs used in the region of study as well as on farm. Subsequently, we relate the efficiency levels to differences in farmers' goals and objectives.

Three different efficiency levels are estimated. These are: (1) an output-oriented measure of technical efficiency; (2) a measure of profit efficiency; and (3) a measure of food efficiency. The first two measures are based on the (standard) procedure as described in, e.g., Ray (2000). The measure of food efficiency, computationally similar to the concept of revenue efficiency, is introduced and described in Chapter 2. The DEA-estimates are further modified to account for the fact that input variables are either fixed in the short run, such as household and farm size, or variable, such as the use of fertilizer or hired labour. The full description of the DEA-models is given in Appendix A.

In Chapter 4, efficiency scores are estimated parametrically by using Stochastic Frontier Analysis. More specifically, in this chapter the relationship between efficiency scores and heterogeneity in soil fertility levels is explored and a detailed description of this method is given.

Chapter 2

Does heterogeneity in goals and preferences affect allocative and technical efficiency? A case study in northern Nigeria.[*]

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[*] This chapter is under review as:
Berkhout, E.D., Schipper, R.A., Kuyvenhoven, A., Coulibaly, O. Does heterogeneity in goals and preferences affects allocative and technical efficiency? A case study in northern Nigeria. Submitted.

Abstract

Household characteristics are commonly used to explain variation in smallholder efficiency levels. The underlying assumption is that differences in intended behaviour are well described by such variables, while there is no a priori reason that this is the case. Moreover, heterogeneity in farmer goals and preferences, in relation to the role of the farm enterprise, are not well documented in developing countries. This research makes a contribution to fill this gap by empirically determining heterogeneity in farmer goals and attitudes in Nigeria through a pair-wise ranking, supplemented with Likert scales. Principal component analysis is used to reduce these data into behavioural factors. We estimate technical and allocative efficiency levels and analyse how these are related to farm characteristics and the identified behavioural factors. The models in which both intended behaviour and farmer characteristics are included give a significantly better fit over models in which only household characteristics are included. These regression results also suggest that the socio-economic environment affects efficiency levels both directly and indirectly, through changes in goals and attitudes. Additional research in rural areas of developing countries should establish how agricultural policies should account for this heterogeneity.

2.1 Introduction

A large body of literature analyses, both through parametric and non-parametric methods, farm production behaviour in rural areas of developing countries. The majority of non-parametric approaches aims to simulate farmer production decisions under various assumptions and scenarios (e.g., Hazell and Norton, 1986). While these provide useful insights in a potential efficient response to exogenous changes, the results are strongly conditional on the assumptions made by the researcher on farmer behaviour. For example, several studies explain observed variation in technical and allocative efficiency levels from household and socio-economic characteristics (e.g., Alene and Manyong, 2006), while other studies estimate household factor demand as a function of prices and household characteristics (e.g., Singh *et al.*, 1986)). These studies thereby circumvent further explicit assumptions on the shape of the utility function. However, these studies make an implicit assumption that the relationship between farmers' production goals and preferences and household characteristics is homogenous in the area of study, while there is no clear reason why this should be the case. While some studies acknowledge the importance of attitudes and production goals, very few actually attempt to quantify these at the micro level.

Risk attitudes, starting from Binswanger (1980); time preferences; and preferences related to cooperation and trust have received considerable attention in field experiments in developing countries (e.g., Cardenas and Carpenter, 2008). On the other hand, very few other attitudes have received attention in empirical research. For example, poorly functioning agricultural markets undoubtedly explain a considerable part of the strong subsistence production-orientation found amongst many smallholder farmers. That said, such imperfections can influence production decisions both in a direct and indirect way. While economic circumstances limit farmers from market-oriented production, farmers might view the production of sufficient subsistence staple crops as their duty. The latter belief can be reinforced by social, natural and economic factors.

The identification and quantification of farmer goals has received considerable attention in developed countries. Van Kooten *et al.* (1986) documented farm goals in Canada, Willock and Deary (1999) in Scotland, while Basarir and Gillespie (2006) documented and quantified differences in attitudes and goals between beef and dairy producers in Louisiana. To determine the effects of these “human factors” several studies have linked farm productivity measures and production choice with farmer attitudes. Penning and Leuthold (2000) found important relationships between farmer attitudes and usage of future contracts in the Dutch hog sector. Amongst Dutch dairy farmers, Bergevoet *et al.* (2004) found that farmers’ objectives and attitudes explain variation in farm size and milk quota. Hence, heterogeneity in farmer attitudes clearly matters in developed countries, while it has received, except for risk attitudes and time preferences, preciously little attention in developing countries.

A few exceptions are Costa and Rehman (1999) who found that goals do affect farm decisions on herd size in Brazil, while Solano *et al.* (2006) related farmer decision-making profiles to farm performance in Costa Rica. Some studies focusing on African smallholder agriculture in relation to productivity explicitly acknowledge the presence and relevance of multiple, sometimes conflicting goals (e.g., Tittonell, 2008), while others have ventured to determine farmer attitudes in relation to specific farm management practices (e.g., Okoba and De Graaff, 2005; Brown, 2006). None to our knowledge have empirically determined and quantified goals and attitudes related to the farm enterprise in general in Sub-Saharan Africa.

The objective of this research is twofold. First, we set to quantify heterogeneity in farm production attributes empirically amongst smallholder farmers in a rural African setting. Furthermore we examine whether a causal relationship between the farmers’ attitudes and production goals and his socio-economic environment and personal characteristics exists. Hence we hypothesize that both exogenous economic factors as well as personal characteristics influence variation in these attitudes and production goals.

Secondly, heterogeneity in these attitudes and goals is expected to translate into different production strategies, which matters to policy-makers since it affects farmer response to agricultural policies. Therefore we expect that differences in farm productivity and efficiency measures, particularly measures of profit, food and soil use efficiency, are a partial result of heterogeneity in these preferences. This in turn we set out to determine empirically. For these aims we collected data from 230 farmers in northern Nigeria.

The remainder of this chapter is organized as follows. In the next section we discuss the theoretical background, thereby relating non-separable agricultural household models to various efficiency measures and the existence of multiple production attributes. In Section 2.3 we discuss the data and the method of analysis, while we present the main findings in Section 2.4. We discuss the results and draw conclusions in Section 2.5.

2.2 Measuring efficiency in an agricultural household model

The core of the literature analysing production behaviour in rural areas starts from the agricultural household model (e.g., Singh *et al.*, 1985). In such a model utility is maximized subject to income, derived from agricultural production and off-farm activities. Equations (2.1)-(2.7) describe the standard model for the case of a household producing a cash crop Q_C and subsistence crop Q_S. Equation (2.1) defines a consumption utility function, based on consumed quantities X_C, X_S of these crops and leisure, l. Equation (2.2) and (2.3) define the production technology of both crops, with output Q_C and Q_S, as a function of farm labour use X_C, X_S and land allocation A_C and A_S respectively[1].

The left hand side of (2.4) defines full income as farm profits Π, augmented with household labour supply T valued at market wage rate w. The right hand side of (2.4) denotes the cost of consumption including costs of leisure time. Profit (2.5) is defined as market value of production minus labour costs. The total labour supply (2,6) equals household labour supply to both crops and leisure consumption l. Finally (2.7) indicates that labour supply to crop i, L_i, equals both household and market supplied labour.

$$U(X_C, X_S, l) \tag{2.1}$$

$$Q_S = Q_S(A_S, L_S) \tag{2.2}$$

$$Q_C = Q_C(A_C, L_C) \tag{2.3}$$

$$\Pi + wT = p_S X_S + p_C X_C + wl \tag{2.4}$$

$$\Pi = p_S Q_S + p_C Q_C - w(L_S + L_C) \tag{2.5}$$

$$T = L_S^h + L_C^h + l \tag{2.6}$$

---

[1] We assume land allocation and all other inputs except labour, to be fixed throughout the remainder of this paragraph. The results derived can easily be transformed to a multiple input case. In the analysis discussed in Chapter 4 multiple variable inputs and outputs are included.

$$L_i = L_i^h + L_i^m \qquad \forall\ i = C, S \qquad (2.7)$$

If a farmer faces perfect in- and output markets, e.g., no significant price differences between farm gate and markets, and perfect credit, land and labour markets, the decision-making process is, and the household model is called, separable. Then utility is maximized by first determining optimal production and profit levels, (i.e., maximize (2.5) subject to (2.2) and (2.3)), yielding Π^*). Next optimal consumption levels can be derived based on Π^* (i.e., optimise (2.1) subject to (2.4)). Profit is maximized when the marginal input productivities, valued at exogenous output prices, equal exogenous unit input costs. Denote resulting optimal production quantities $Q_S^{\Pi*}$ and $Q_C^{\Pi*}$ respectively.

$$p_C \frac{\partial Q_C}{\partial L_C} = w\,,\ p_S \frac{\partial Q_S}{\partial L_S} = w \qquad (2.8)$$

By (2.6) an increase in commodity prices leads to efficient production quantities at which marginal productivities are lower. Optimal consumption decisions are found by equating marginal utility of consumption to exogenous commodity prices multiplied by the multiplier associated with the income constraint (2.8).

$$\frac{\partial U}{\partial X_C} = p_C \lambda\,,\ \frac{\partial U}{\partial X_S} = p_S \lambda \text{ and } \frac{\partial U}{\partial l} = w\lambda \qquad (9)$$

A large body of research in rural agriculture in SSA focuses on the production component (2.5) of the model by determining measures of production efficiency (Arega *et al.*, 2006; Binam *et al.*, 2004). Hereby output (input)-efficiency is defined as the difference between actual output (input) and maximum (minimum) feasible output (input) given a certain input (output) level, by using a radial distance function, thereby assuming equi-proportionate expansion (reduction) in output (input) levels.

In addition to these measures, commonly referred to as technical efficiency, economic efficiency (i.e., cost, revenue, profit) measures have been used. All measures are expressed as the distance between actual cost/revenue/profit level and optimal feasible costs/revenue/profit level, and depend on changing input or output levels and reducing technical inefficiency. The concept of profit and technical efficiency is illustrated in Figure 2.1 for one crop with variable labour input L_S and production $Q_S = Q_S(L_S)$.

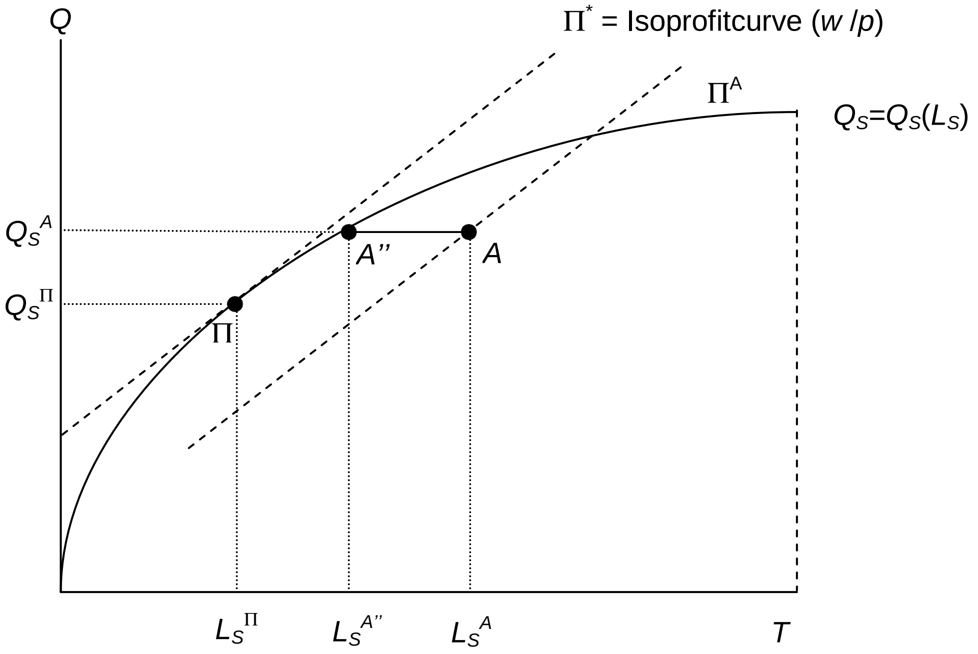

Figure 2.1: Profit Efficiency – single crop

A farmer producing at point *A*, (Q_S^A, L_S^A), is technically inefficient, as the production frontier shows that point *A''*, $(Q_S^A, L_S^{A''})$, with reduced labour use $(L_S^{A''} < L_S^A)$, while holding output constant, is feasible as well. However, the wage rate exceeds the value of marginal returns to labour at point *A''*, and decreasing total labour supply to point L_S^Π is economically efficient. Hence, profits are maximized at Π^*, where the marginal productivity of labour is tangent to the isoprofit curve with slope w/p_S (2.8). Furthermore, point *A''* is scale, and/or in the case of multiple in- and outputs, allocatively inefficient and point *A* is scale/allocatively and technically inefficient with $\Pi^A < \Pi^{A''} < \Pi^*$. A full measure of economic or profit efficiency (EE) is provided by $\Pi^A / \Pi^* \leq 1$. The total profit foregone due to inefficiency, normalised at the observed cost level C_A, can further be decomposed by identity (2.10) into profit lost due input-oriented technical inefficiency (TE) and profit lost due allocative and/or scale inefficiency (AE) (e.g., Ray, 2004, p.233).

In (2.10), Π^* is the profit efficient level in Figure 2.1 that can be identified through the application of a Data Envelopment Analysis (DEA) model (Appendix

A.3, equations A.1 - A.6). Π^A is the level of profit based on the observed level of output and observed use of labour, $\Pi^A = p_S Q_S^A - w L_S^A$, and $\Pi^{A''}$ is the level of profit when input-oriented technical inefficiency is eliminated, $\Pi^{A''} = p_S Q_S^A - w L_S^{A''}$. The latter equals: $\Pi^{A''} = p_S Q_S^A - \alpha w L_S^A$, with α being a measure of input-oriented technical efficiency. This measure α can be identified through the application of another DEA-model (Appendix A.3, equations A.8 - A.12).

$$\frac{\left(\Pi^* - \Pi^A\right)}{C_A} = \frac{\overbrace{\left(\Pi^* - \Pi^{A''}\right)}^{AE}}{C_A} + \frac{\overbrace{\left(\Pi^{A''} - \Pi^A\right)}^{TE}}{C_A} \qquad (2.10)$$

Then, the last term in (2.10) reduces to (1 - α) as shown in (2.11) and the normalised profit lost due to allocative inefficiency $\left(\frac{\Pi^* - \Pi^{A''}}{C_A}\right)$ in (2.10) can be determined.

$$\frac{\left(\Pi^{A''} - \Pi^A\right)}{C_A} = \frac{\left(p_s Q_s^A - \alpha w L_s^A\right) - \left(p_s Q_s^A - w L_s^A\right)}{w L_s^A} = (1 - \alpha) \qquad (2.11)$$

Note that when profit efficiency estimates are close to 1, farm production decisions reflect profit-maximizing behaviour and separability of the household model holds approximately. Another commonly used method to determine whether separability holds is by estimating input demand functions based on (2.8) which, under the assumption of separability, should be a function only of the production technology and input prices. If household characteristics do influence production decisions, separability is usually rejected. Most studies find that in developing countries, the cases for which separability holds are an exception, with imperfect markets being the rule (e.g., Jacoby, 1993; Kevane, 1996).

With market failure(s), production and consumption decisions can likely not be considered separately, but instead optimal production decisions are described by different attributes such as cash needs and subsistence consumption requirements. Furthermore, the relative importance of certain attributes is likely to differ from farmer to farmer, amongst others, reflecting their integration into input and output markets. Moreover separability is likely to hold for some farmers but not all, as shown by Carter and Yao (2002).

Let us assume the extreme case in which a farmer is completely isolated from markets. This could be in part due to the non-existence of certain output and input markets (e.g., due to geographic isolation and/or failing credit and insurance markets), which is possibly further aggravated by price and yield risk, or because a farmer chooses to produce in isolation from markets. The utility function (2.12) is defined such that utility depends on the consumption of energy (*F*) (or protein) and leisure. Note that efficient production decisions (2.8) are invariant to the shape of the utility function under separability. Again a farmer can grow both crops but does not participate in markets. Both the crops can be consumed, but the nutritional content per unit of production of Q_s is considerably higher: $\eta_S > \eta_C$. Energy consumption is defined as (2.13).

$$\text{Max } U(F, l) \tag{2.12}$$

$$F(Q_C, Q_S) = \eta_C Q_C(L_C) + \eta_S Q_S(L_S) \tag{2.13}$$

First order conditions of maximizing (2.11) subject to (2.12), the production functions (2.2), (2.3), and labour restriction (2.6), reduce to:

$$\frac{\partial U}{\partial F}\frac{\partial Q_C}{\partial L_C}\eta_C = \frac{\partial U}{\partial F}\frac{\partial Q_S}{\partial L_S}\eta_S = \frac{\partial U}{\partial l} \tag{2.14}$$

By (2.14) a farmer chooses production such that marginal utility derived from applying one extra unit of labour to production equals marginal utility from one extra unit of leisure. Denote the optimal production quantities from (2.14) as $Q_S^{\Phi*}$ and $Q_C^{\Phi*}$, i.e., food efficient levels.

The concept of food efficiency is illustrated for a single crop model in Figure 2.2. A further simplification is made that utility is only derived from consumption of energy. The dotted line in Figure 2.2 represents total energy produced, which is a constant fraction of total output. Again, a farmer producing at (Q_S^A, L_S^A) is technically inefficient, similar to the case of profit efficiency. A farmer aiming to maximize food production will use the full labour supply *T* to produce, in the case of a single crop, at corner point Φ. Hence, $(Q_S^{A'}, L_S^A)$ is food inefficient and a measure of food efficiency is given by (2.15). Similar to the concept of revenue efficiency, food efficiency (FE) can be decomposed into output-oriented technical (TE) and allocative efficiency (AE).

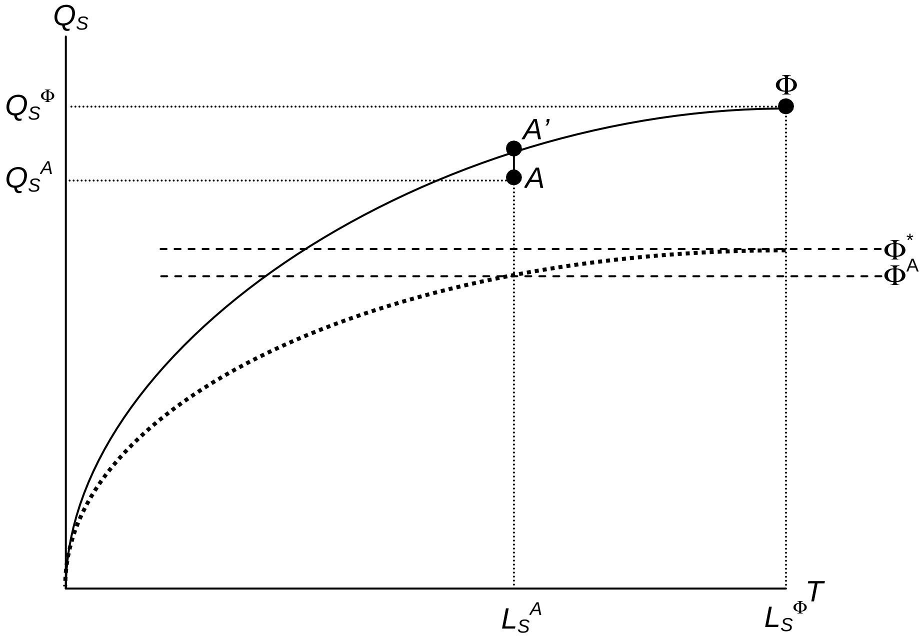

Figure 2.2: Food Efficiency – single crop

$$E^\Phi = \frac{\Phi^A}{\Phi^*} = \underbrace{\overbrace{\frac{\Phi^A}{\Phi^{A'}}}^{TE}\overbrace{\frac{\Phi^{A'}}{\Phi^*}}^{AE}}_{FE} \tag{2.15}$$

The case for two crops (cash and subsistence) is illustrated in Figure 2.3. Here production of the subsistence crop reads from the left, and remaining labour is used in the production of the cash crop (from the right). The two lightly dotted curves indicate nutrients produced, as a constant fraction of total output, for each of the two crops. The bold dashed curve shows total energetic value produced, the maximum of which denotes food efficient production levels. At this maximum, labour supply to the subsistence crop equals L_S^Φ and to the cash crop $T - L_S^\Phi$. At this point the marginal energetic value of labour use in one crop equals the marginal energetic value lost when removing one unit of labour from the other crop. Finally labour supply and production in both Figure 2.2 and 2.3 is lower if leisure is a normal good, hence the depicted food efficient production levels are theoretical upper bounds based on the case in which no leisure is consumed.

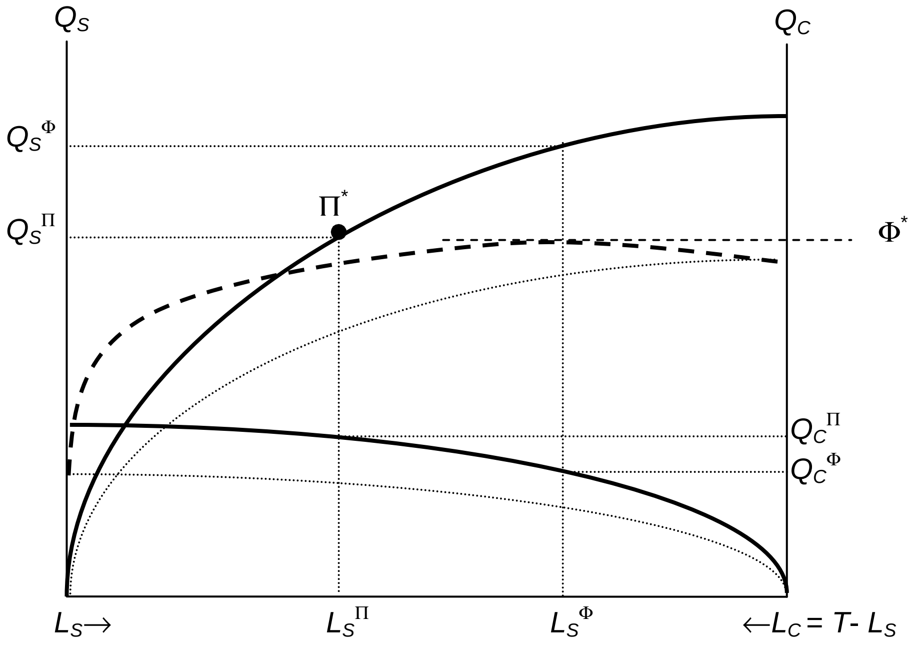

Figure 2.3: Food Efficiency – two crops

The two formulated cases above, profit and food efficiency, reflect two extremes. The former in which a farmer produces and consumes while participating in all markets, the latter in which he consumes and produces in isolation from all markets. In reality farmers are likely to produce and consume somewhere in between, with this choice being influenced by local circumstances, the farmers' endowment and his personal attitudes and preferences. To relate both cases, we introduce weights, g_Π and $g_\Phi = (1 - g_\Pi)$, such that[2]:

$$Q_S^A \approx g_\Pi (Q_S^{\Pi*} - Q_S^{\Phi*}) + Q_S^{\Phi*} \tag{2.16}$$

$$Q_C^A \approx g_\Pi (Q_C^{\Pi*} - Q_C^{\Phi*}) + Q_C^{\Phi*} \tag{2.17}$$

Hereby $g_\Pi = 1$ reflects the case in which a farmer produces at optimal profit levels, and $g_\Pi = 0$ the case in which a farmer is producing at optimal food levels. Hence for intermediate values a farmer implicitly optimises a combination of the objective to maximize profits and to satisfy consumption preferences from his farm production.

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[2] Note that it is assumed that $Q_S^A \in [Q_S^{\Pi^*}, Q_S^{\Phi^*}]$ and similarly $Q_C^A \in [Q_C^{\Pi^*}, Q_C^{\Phi^*}]$. This implies, by (2.16) and (2.17), that $g_\Pi + g_\Phi \approx 1$. It is likely that actual production quantities of farmers are somewhere in between these two extreme cases.

We define actual profit and food production as (2.17) and (2.18) respectively, and define profit efficiency E^{Π} and food efficiency E^{Φ} as (2.19) and (2.20).

$$\Pi^{A} \approx \sum_{i=S,C} p_i (g_{\Pi} Q_i^{\Pi*} + g_{\Phi} Q_i^{\Phi*}) \tag{2.18}$$

$$\Phi^{A} \approx \sum_{i=S,C} \eta_i (g_{\Pi} Q_i^{\Pi*} + g_{\Phi} Q_i^{\Phi*}) \tag{2.19}$$

$$\mathrm{E}^{\Pi} = \Pi^{A} / \Pi^{*} \leq 1 \tag{2.20}$$

$$\mathrm{E}^{\Phi} = \Phi^{A} / \Phi^{*} \leq 1 \tag{2.21}$$

Hereby Π^{*} and Φ^{*} are defined by (2.8) and (2.14) respectively. Finally, note that $\mathrm{E}^{\Pi} = \mathrm{E}^{\Pi}(g_{\pi})$ increases for decreases in $|1 - g_{\Pi}|$ and $\mathrm{E}^{\Phi} = \mathrm{E}^{\Phi}(g_{\Phi})$ increases for decreases in $|1 - g_{\Phi}|$. Furthermore by construction, the expected correlation between food and profit efficiency levels is negative: $Cov(\mathrm{E}^{\Pi}(g_{\pi}), \mathrm{E}^{\Phi}(1 - g_{\pi})) \leq 0$.

While environmental factors (i.e., rainfall and soil fertility) as well as managerial quality to a large degree explain levels of technical efficiency, measures of allocative efficiency are a direct result of farmer behaviour. Hence, we view differences in allocative efficiency as the result of behavioural heterogeneity, i.e., heterogeneity in livelihood strategies.

We assume the weights g_{Φ} and g_{Π} are a function of the farmers' goals and personal preferences and attitudes, *z*. These preferences include the perceptions and attitudes of farmers on the role agriculture play in his livelihood. For example, social and personal perceptions might be such that agriculture primarily serves to meet subsistence demands, hence giving a rise to g_{Φ}. These goals themselves are likely in part explained by the socio-economic and biophysical environment in which a farmer operates. This is captured by (2.22).

$$g_{\Pi} = g_{\Pi}(z(K), K) \Leftrightarrow E^{\Pi}(g_{\Pi}) = \mathrm{E}\Pi(g_{\Pi}(z(K), K)) \tag{2.22}$$

In (2.22), variables in vector *K* reflect various market imperfections such as transport costs and participation in credit and insurance markets, and farmers' assets (i.e., natural, financial, human, social and physical capital). Note that some variables can have both direct and indirect effects, through farmer goals and preferences, on production decisions.

Figure 2.4 illustrates this approach in a conceptual framework, thereby relating farmer goals and objectives to livelihood assets and livelihood indicators. The figure is adapted from the Sustainable Livelihoods Framework (Ellis, 2000). In the framework it is assumed that trends and shocks, livelihood assets and partly endogenous factors such as social relations and institutions, result in livelihood strategies, as denoted by the continuous arrows in the figure. At the same time these livelihood strategies give rise to the objectives and attitudes of a farmer on the role of agriculture in his livelihood strategy (i.e., g_{Π} or g_{Φ}). Finally, these strategies lead to farm and non-farm strategies, and hence to livelihood and sustainability indicators, while at the same time direct effects on livelihood indicators are possible. In this chapter we further quantify the relationships as indicated by the dashed lines. The next section describes the data collection, including the measurements of goals and objectives, as well as the determination of efficiency measurements.

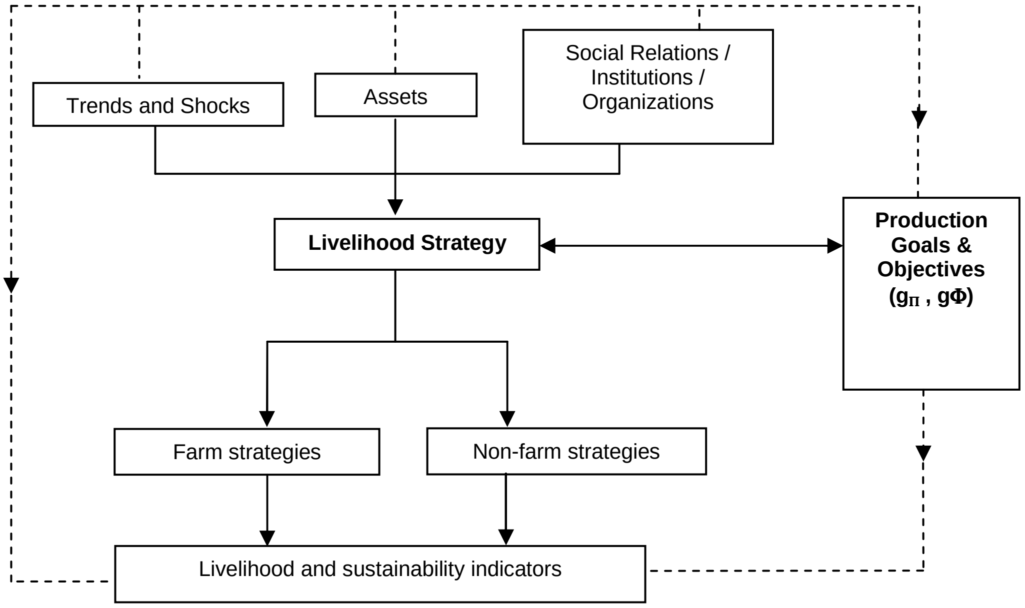

Figure 2.4: Conceptual framework farmer decisions

2.3 Estimation approach and data

2.3.1 Estimated model

Section 2.2 argues that farmer production decisions are aimed at supplying the market, at meeting own consumption, or a combination of both. Such heterogeneity in objectives is illustrated in Figure 2.5. While some farmers (i.e., group A) aim at supplying goods to the market (i.e., are relatively more profit efficient), others primarily aim to meet domestic demand for food (group C), while again others fall somewhere in between (group B).

Hence we relate observed efficiency levels to both household characteristics and heterogeneity in goals and attitudes. First efficiency measures E^s are determined, through Data Envelopment Analysis (DEA). These measures are expressed on a scale between 0 and 1, with 1 reflecting full efficiency. Observed efficiency levels are then related to household characteristics as in (2.23)[3], with K_i a vector of household characteristics such as age, level of education and distance to markets. Due to the censored nature of the observations, (2.23) is estimated by a Tobit regression.

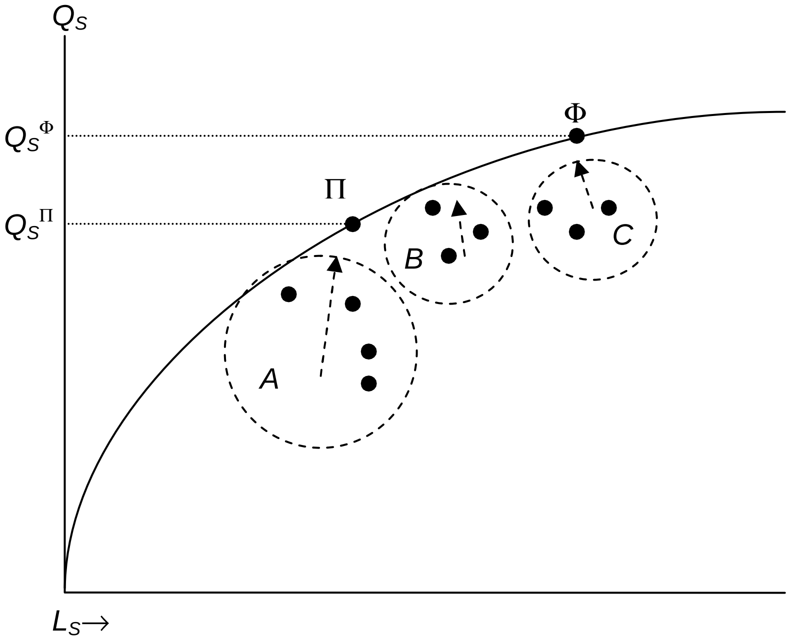

Figure 2.5: Heterogeneity in objectives

In our approach we hypothesize that efficiency levels can be explained by household goals and preferences, in addition to household characteristics. We include these

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[3] We suppress the farmer subscript in the formulas presented

through “behavioural” variables z_j, and are interested whether equation (2.23) better describes the observed variation in efficiency levels.

$$E^s = \beta_{0s} + \sum_{i=1}^{N} \beta_{is} K_i + \varepsilon_{1s} \tag{2.23}$$

$$E^s = \beta_{0s} + \sum_{i=1}^{N} \beta_{is} K_i + \sum_{j=1}^{M} \gamma_{js} z_j + \varepsilon_{1s} \tag{2.24}$$

It is possible that the behavioural variables z_j are related to the household characteristics K_i (2.24):

$$z_j = \alpha_{0j} + \sum_{i=1}^{N} \alpha_{ij} K_i + \varepsilon_{2j} \tag{2.25}$$

Hence if household preferences and goals indeed have a direct effect on efficiency levels, and if these preferences are fully described by household characteristics (2.25), then by substituting (2.25) into (2.24), equation (2.26) can be estimated directly.

$$E^s = \beta^*_{0s} + \sum_{i=1}^{N} \beta^*_{is} K_i + \varepsilon^*_{1s} \tag{2.26}$$

This reflects the commonly estimated case were z_j is unobserved. The parameter estimates of household characteristics K then capture both direct and indirect effects (through z_j), with $\beta^*_{is} = \beta_{is} + \sum_{j=0}^{M} \gamma_{js} \alpha_{ij}$ and $\varepsilon^*_{1s} = \varepsilon_{1s} + \sum_{j=1}^{M} \gamma_{js} \varepsilon_{2j}$.

If the inclusion of behavioural factors z_j in (2.24) does give a significantly better fit compared to direct estimation of (2.23), we should conclude that household preferences and goals do give additional explanation to observed efficiency levels.

It is however not directly obvious whether (2.24) can be estimated consistently. If the causality is postulated correctly as in (2.24) and (2.25), then both equations describe a fully recursive system. Then, if K and ε_{2j} are independent and the error terms ε_{1s} and ε_{2j} are uncorrelated, both equations can be consistently estimated by a Tobit regression (e.g., Greene, 1997, p.737). Nevertheless there are several reasons why the error terms might be correlated. First, measurement errors in K would not only render consistent estimation of (2.25) impossible, but would also induce correlation between both equations as K enters both. Secondly, unobserved variables such as local climatic conditions might influence both behavioural factors and efficiency levels. This omitted variable bias then carries over to both equations. Furthermore, efficiency levels and intended behaviour might suffer from simultaneity bias. We therefore test if endogeneity affects the estimated Tobit models. By estimating (2.25) variables are identified which correlate with z_j but not with efficiency levels E_s and serve as potential instruments. A Wald test on exogeneity is used to test if z_j need to be instrumented (e.g., Cameron and Trivedi, 2005, p. 561).

2.3.2 Data collection

Data is collected in the 2006-cropping season for 230 farmers in seven villages (Figure 2.6) in the Northern Guinea and Soudan Savanna in northern Nigeria. The region is characterized by a unimodal rainfall pattern, from June till September. Mixed cropping systems with cereals (maize, sorghum, millet) and legumes (cowpea, groundnut) dominate the region. Nevertheless, other crops such as rice, sugarcane and tuber crops are frequently cultivated, as well as vegetables to supply Nigeria's urban population.

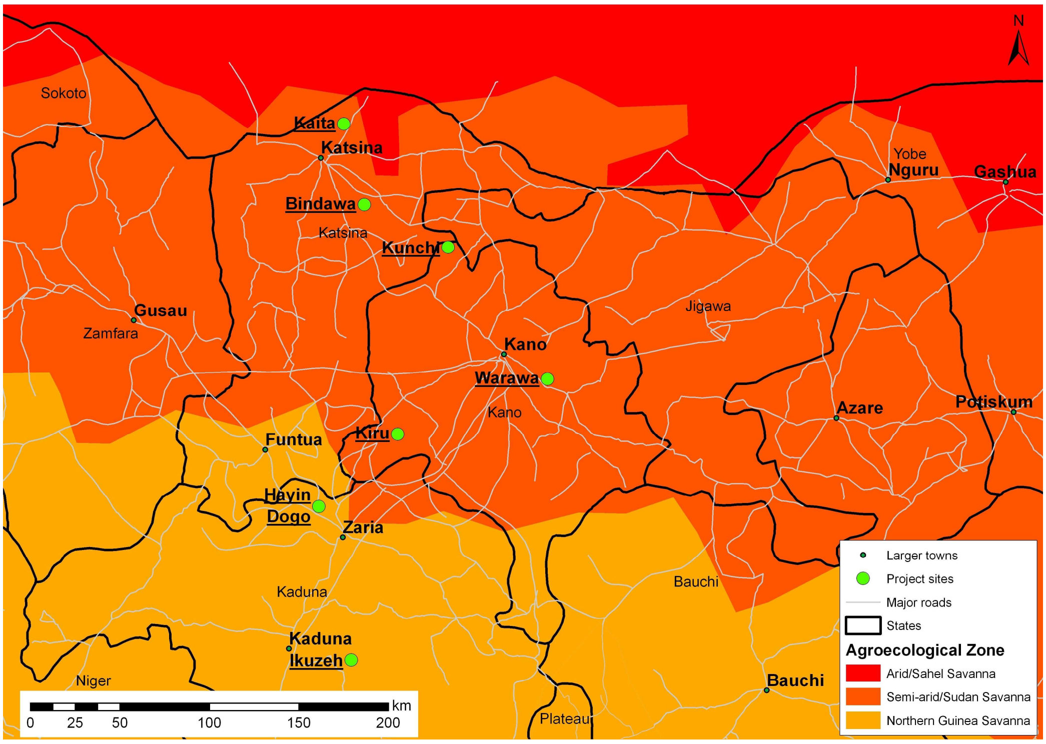

Figure 2.6: Sites data collection

The village selection is based on differences in market access, population pressure and production potential (differences in soils and climate). In each village a list of inhabitants is established with village elders, from which 30 to 40 farm households are randomly selected. At this point all selected farmers are asked if they are willing to participate in the survey, which consists of three different survey instruments administered at different moments in time. All three instruments were extensively pre-tested in a non-sample area. Village-based and IITA-employed enumerators have carried out the data collection. The village-based enumerators (either extension agents or school teachers) have received training before the data collection to refresh their interview techniques. The third survey, eliciting farmers' goals and production attributes, is administered by an experienced IITA-enumerator due to the more complex nature of the questions.

In the first survey information on household composition was elicited, including age, education level and income sources for each member of the household, farm assets, plot sizes and their perceived production potential, farm tools, non-farm assets (bicycles, radios, etc.), livestock ownership (per type of animal), and a number of general questions such as received agricultural training and contact with extension agents. The enumerators administered the second survey shortly after harvest. At this point production data (harvested products and quantities) and detailed input data (fertilizer use, hired labour, pesticide use) were collected. Table 2.1 and 2.2 describe the major characteristics observed.

Table 2.1: Village characteristics

Local Government Area	Household Size	% of which are children	% having other income sources	Assets (Farm)[1]	Assets (Non-farm)[1]	Herd Size	% of which are small ruminants
	#			Naira	Naira	TLU	
Kaita	5.21	51	39	1,138	14,374	1.49	59
Bindawa	8.05	63	17	7,651	36,985	3.73	28
Kunchi	8.83	58	07	31,529	22,609	6.14	44
Warawa	8.41	49	50	34,295	20,445	1.64	58
Kiru	5.72	74	20	9,377	20,463	1.92	54
Hayin Dogo	6.47	44	37	7,339	49,777	5.08	72
Ikuzeh	7.34	53	29	4,609	20,947	0.90	25

Data based on village-level surveys in Kaduna, Kano and Katsina states in 2006 and 2007.

[1] 130 Naira approximately equals 1 USD

Table 2.2: Production data

LGA	Fertilizer (kg ha^{-1})	Manure (kg ha^{-1})	Pesticides / Herbicides (liter ha^{-1})	Land to Labour ratio (men ha^{-1})	Hired Labour (Naira ha^{-1})^{1}	Farm Size (ha)	Fallow (% of farm)
Kaita	94	1,822	0.67	1.31	1,379	1.47	0.00
Bindawa	83	1,417	0.25	0.76	3,905	3.66	0.00
Kunchi	90	1,955	0.03	1.49	1,719	2.56	11.89
Warawa	29	2,333	0.00	0.98	3,931	3.00	0.00
Kiru	264	946	0.00	0.75	10,797	3.17	0.00
Hayin Dogo	173	197	0.06	0.82	2,311	5.07	0.00
Ikuzeh	32	24	0.73	0.86	505	5.80	0.00

Data based on village-level surveys in Kaduna, Kano and Katsina states in 2006 and 2007.
[1] 130 Naira approximately equals 1 USD

The third survey consists of two parts; a fuzzy pair-wise ranking and a set of Likert-scale questions. Both parts were translated into the local language (Hausa). The objective of the fuzzy pair-wise ranking (e.g., Van Kooten *et al.*, 1986) was carefully explained, such that the farmer fully understood the methodology, before the ranking started. In this ranking farmers were asked to indicate their preferences for five goals. These goals are: getting the highest net benefits from farming; getting the highest subsistence food production; minimizing the risks of farming; safeguarding the soil for future generations; and minimizing labour use in agriculture. Each pair was visualized clearly to the farmer, as shown in Figure 2.7, whereby a line drawn between two attributes represents the relative preference.

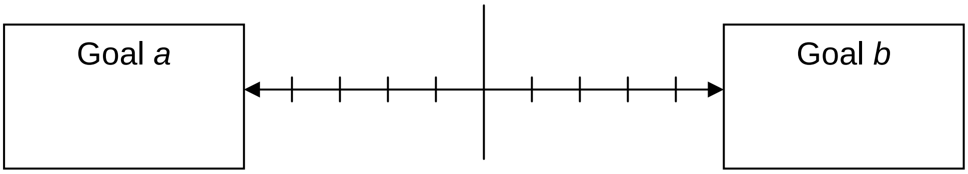

Figure 2.7: Visualization of goals in pair-wise goal ranking method

A farmer *i* was then asked to value the relative importance by indicating a cross on a line connecting the two attributes, *a* and *b*, thereby yielding a score $R_{i,a,b}$. A cross in the centre represents equal importance, giving $R_{i,a,b} = R_{i,b,a} = 0.5$. A deviation from the centre indicates more importance of one attribute, with $R_{i,a,b} > R_{i,b,a}$ for some *a* and *b*. This was repeated for each possible pair of goals $a, b \in G$. We used normalized scores such that $R_{i,a,b} + R_{i,b,a} = 1$. Finally aggregated values are computed for each of the goal weights by applying (2.27) (Van Kooten *et al.*, 1986), where $I_{i,a}$ represents the aggregate preference of farmer *i* for goal *a*.

$$I_{i,a} = 1 - \left(\sum_{b=1}^{G} R_{i,b,a}^{2} /(|G|-1) \right)^{1/2} \tag{2.27}$$

The aim of this aggregation is to calculate the Euclidean distance between an observed ranking and an exact scoring, i.e., a line segment in the space of rankings for which one goal strictly dominates all others. The Euclidian distance between an observed ranking and the line segment for which goal *a* strictly dominates all other goals is measured by $\left(\sum_{b=1}^{G} R_{i,b,a}^{2} \right)^{1/2}$. The distance is subsequently normalised by dividing it by the maximum value it can take, $(|G|-1)^{1/2}$. The minimum value the distance can take is zero, which occurs when the observed ranking falls exactly on the line segment and then, by (2.27), $I_{i,a}$ equals 1. Hence, these aggregated values lie between zero and one, with larger values reflecting a greater intensity or preference for that specific goal and for $I_{i,a} > I_{i,b}$ attribute *a* is strictly more important than attribute *b* to farmer *i*. Moreover, the aggregation maintains transivity, if transivity holds in the ranking itself.

Next, the farmer responded to 17 questions (Appendix A, Table A.1), giving statements on, and aimed at further measuring, each of these attributes. The farmer was asked to state his opinion on each question and respond in the format Agree/ Neutral/ Disagree or Don’t know. The enumerator wrote down the answer given. We did not opt to include a more extended scale, as such nuances would not be captured easily in the process of translation.

2.3.3 Determining efficiency levels

To measure efficiency levels E^{Π} and E^{Φ}, Data Envelopment Analysis (DEA) is used. Charnes *et al.* (1976) introduced DEA, shortly followed by its parametric counterpart, stochastic frontier analysis (SFA) (Aigner *et al.*, 1977; Meeusen and Van den Broeck, 1977).

The advantage of using DEA over SFA is the flexibility to account for multiple in- and outputs; whereas estimation problems related to endogeneity plague such estimations in SFA. Although Kumbhakar (1996) proposes a method to determine efficiency levels by applying SFA for such cases, the method is difficult to implement and has not been used frequently. Furthermore a DEA-program to determine profit efficiency can easily be modified to account for different attributes such as food efficiency. A major disadvantage of DEA is that the method is consistent, but biased in small samples. Nevertheless, some studies find only small differences between SFA and DEA estimates (e.g., Arega *et al.*, 2006), thus suggesting the two methods are interchangeable for sufficiently large samples. The estimation bias in small samples is of concern especially in a two-step method in which efficiency scores are explained, as in our analysis. Simar and Wilson (2007) propose a method to improve the consistency. However, some studies find minor changes when applying the Simar and Wilson method (e.g., Afonso and St. Aubyn, 2006). We therefore opt not to correct for this small sample bias.

We estimate profit efficiency (E^{Π}) as the distance between actual profit level and maximum achievable profit level, given observed prices for variable in- and outputs. Food efficiency (E^{Φ}) is measured as the distance between actual and potential maximal food production, both of which are feasible given the observed input bundle used, in Mega Joules. This approach is similar to the concept of revenue efficiency in which instead of market prices, relative nutritional content (FAO, 2006) is used.

We further decompose food inefficiency into technical inefficiency and allocative inefficiency by applying (2.15). We estimate an additive decomposition to obtain total normalised profit lost due to input-oriented technical inefficiency and profit allocative inefficiency, based on (2.10). The full description of the DEA-models used is provided in Appendix A (Sections A.2, A.3 and A.4), while the programs are written and solved in AIMMS 3.6.

In the area of study 22 different crops are grown (median per farmer: 3), and 8 different kinds of inputs are used (median per farmer: 5). As the number of in- and outputs included influences the efficiency levels, outputs are aggregated in four main classifications, cereals (excluding rice), legumes, high-value crops (roots, tubers and vegetables), rice, and sugarcane. We do not aggregate rice and sugarcane into the other outputs, as both of them require a special land input (fadama (riverbed) fields). Furthermore their prices and nutritional values per unit output differ considerably from other cereal or high-value crops. On the input side only the three different types of fertilizer are aggregated (NPK, Urea, SSP). A decomposition of fertilizer use into the different active components would not have been more accurate due to common practices of adulterating fertilizer. Given the distinct roles household labour, farm size, fadama size, pesticide use, manure and hired labour play in the production process, these are maintained as separate inputs in the DEA models. No data was available to further express pesticide use into quantities of active components.

Prices, as well as nutritional and soil fertility values and soil fertility use, used for each of these outputs are a weighted average of prices of individual crops, in which the weights represent the share of production of a crop in total production of this aggregated output (in kg). In a similar way prices for the aggregated fertilizer variable are calculated. Finally some inputs are fixed in the short-run (household labour available to agriculture, farm and fadama size). Hence these variables cannot be purchased or sold on the market (at least in the short run), and the DEA model is modified for this (Ray, 2004, p. 220).

2.4 Estimation results

2.4.1 Identifying heterogeneity in production attributes

Table 2.3 shows aggregated scores, by applying (2.27), from the fuzzy pair-wise ranking. It appears that staple food production and sustainability are the most important attributes to farmers in the area of study, followed by risk aversion, while gross margins and labour use minimization are relatively unimportant.

Table 2.3: Means (and standard deviations) of goals in pair-wise ranking

Goal	Gross Margin	Staple food production	Risk aversion	Labour use	Sustainability
Mean (standard deviation)	0.18 (0.14)	0.65 (0.28)	0.41 (0.20)	0.07 (0.09)	0.64 (0.28)

We further compared the ordering of the aggregated scores with the scores on the individual pairs. These are fully consistent for 77% of the sample, while for the remaining observations one to three of the individual pairs are inconsistent with the aggregated scores. Given this small number we tend to believe transitivity is well maintained in the aggregated scores.

Table 2.4: Factor loadings

Factors Questions	1	2	3	4	5	6	7	8	9
Q1	0.14	-0.02	-0.03	-0.09	0.01	**0.63**	0.01	0.00	-0.21
Q2	0.13	0.03	0.19	-0.06	-0.03	**-0.73**	-0.12	-0.02	-0.12
Q3	0.15	-0.19	-0.41	-0.01	**0.55**	0.05	0.15	0.31	0.03
Q4	0.09	-0.03	0.12	0.06	-0.03	**0.72**	-0.23	0.02	0.25
Q5	-0.15	**0.61**	0.14	-0.06	**0.60**	-0.02	0.01	0.08	-0.01
Q6	0.02	**0.82**	0.00	0.05	0.15	-0.03	0.07	-0.02	0.08
Q7	**0.60**	-0.02	0.21	0.01	0.08	0.10	0.25	0.22	-0.22
Q8	0.19	-0.25	-0.08	0.20	**0.50**	0.01	-0.11	-0.21	0.38
Q9	-0.01	0.20	0.07	-0.03	**0.82**	-0.01	-0.05	-0.06	-0.05
Q10	**0.84**	0.07	0.02	0.07	0.02	-0.01	-0.11	-0.05	0.12
Q11	0.02	0.20	0.07	0.04	0.07	0.27	**0.55**	0.06	-0.30
Q12	0.31	0.07	**0.82**	0.02	0.00	-0.01	0.05	0.03	0.01
Q13	0.14	**0.76**	-0.01	0.06	-0.08	-0.03	0.05	-0.06	-0.01
Q14	**-0.75**	-0.05	0.10	0.15	0.02	-0.06	-0.19	0.03	0.08
Q15	-0.04	0.07	-0.28	0.09	0.05	0.02	-0.03	**0.67**	-0.14
Q16	-0.08	0.10	-0.07	-0.01	0.02	0.10	0.08	0.07	**0.80**
Q17	0.32	0.01	-0.01	0.24	0.07	-0.15	**0.56**	0.12	0.06
Gross Margin	0.07	-0.11	0.12	-0.05	-0.06	0.01	0.03	**0.83**	0.18
Staple Food Production	0.07	0.00	-0.13	**-0.89**	-0.03	-0.06	0.24	-0.16	0.07
Risk aversion	-0.03	-0.02	-0.20	0.19	0.15	0.11	**-0.76**	0.13	-0.21
Labour use	-0.27	-0.05	**0.77**	-0.03	0.03	-0.11	0.21	-0.14	-0.13
Sustainability	0.00	0.11	-0.13	**0.86**	-0.04	-0.04	0.27	-0.13	0.08

Q1 to Q17 refer to questions 1 to 17. These questions are described in Appendix A. The five rows at the bottom refer to the aggregated preferences for production goals obtained by applying (2.26). The questions and preferences in bold most strongly relate to the identified factors.

Principal component analysis is used to reduce the data from the ranking and the additional questions administered (Table 2.4). The analysis is done for both data sets separately and jointly. As the joined principal component analysis is similar to the separate analyses, we stick to the latter. Various rotations are used to facilitate easier interpretation of the factors obtained, though with largely similar results. The results and an interpretation of the observed factors are given in Table 2.5. We refer to these factors, i.e., variables z_j, as the behavioural factors in the remainder of the document. The results show that nine factors explain 68% of total variation observed.

Only the factors 3, 4, 7 and 8 correlate with the weights from the pair-wise ranking. This is disappointing as the additional questions are meant to provide a robustness check of the methodology used. Here factor 4 solely consists of the inverse negative relationship between sustainability and subsistence production. Clearly a lower importance of subsistence production from agriculture is associated with increasing importance of maintaining soil fertility levels. A strong importance of minimizing labour use on the farm relates to factor 3, while the goal to maximize gross margins in agriculture relates to factor 8.

The other identified factors relate to risk averting behaviour (factor 1); a drive to invest in a sustainable farm business (factor 2); the view that subsistence crop production is a duty (factor 6). Furthermore both factors 7 and 9 relate to a strong desire to seek exit from agriculture. Finally, factor 5 indicates a desire of being a successful farmer and, at the same time, a bit confusingly, relates to stronger importance of risk aversion.

Table 2.5: Factor analysis

Factor	Variation explained	Cumulative variation explained	Higher scores reflect:
1	11.27	11.27	Risk averting behaviour
2	10.02	21.29	Drive to invest in farm business
3	9.49	30.78	Minimize labour use, cannot invest in soils
4	7.57	38.35	Safeguard soil resources for future use
5	6.67	45.03	Wants to be a successful farmer in the future
6	6.28	51.30	Subsistence crop production is one's duty
7	6.03	57.34	Seeks exit from agriculture
8	5.58	62.92	Maximizing financial benefits from farming
9	4.84	67.75	Finds no pleasure in farming

2.4.2 Relating socio-economic variables to heterogeneity in production attributes

In the second step the behavioural factors are regressed on both village dummies (Kaita is used as reference village) and data on household level (Table 2.6). Although we do find significant relationships between the background of farmers and their attitudes, the explained variation is low. In most estimations the adjusted R^2 ranges from 0.11 to 0.53, while only factor 1 is explained at a considerably higher level (adjusted R^2: 0.55). Hence a considerable part of the variation in attitudes and preferences cannot be explained from commonly observed farm-level data.

A number of the effects are as expected. Most notably risk aversion (factor 1) declines with household size and education level. Furthermore it strongly correlates with village dummies, whereby risk aversion appears to decline for increasing levels of rainfall. Again the location of the household strongly relates to the desire to minimize labour use (factor 3), with additional effects from variables such as other sources of income. Finally, the desire of being a successful farmer (factor 5) increases with household size, education level and other sources of income, while it decreases with livestock ownership and effective labour supply to the farm. The remaining

Table 2.6: Relating behaviour factors to socio-economic characteristics

	Factor	1	2	3	4	5	6	7	8	9
	Adjusted R^2	0.55	0.16	0.33	0.21	0.20	0.11	0.25	0.14	0.26
	p-value	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00
	Exogenous variables:									
Human capital	Household Size	-0.21				0.70				
	Labour supply to farm					-0.39				0.30
	Age household head		-0.62				0.59	0.41	-0.65	-0.49
	Average age household members						-0.34		0.80	
	Education level (Koranic or primary)					0.39				
	Education level (secondary or higher)	-0.35				0.67				
	Received agricultural trainings							-0.65		
Natural capital	Farm size			-0.14						
	Distance to farm					0.19				
	Farm quality		0.53							
	Distance to market			0.37						
Financial capital	Livestock ownership				0.15	-0.28				
Physical capital	Value of assets			-0.09						
Other	Receives remittances				-0.40					-0.35
	Other income sources (household head)			0.26					0.30	
	Other incomes sources (% of others)		0.69	-0.57		0.92			-0.78	-0.42
Village dummies	Bindawa	-0.75		-0.83						
	Kunchi	-1.62		1.38					0.81	
	Warawa	-1.51		0.33	-0.48	-0.79	-0.40		-0.62	-0.67
	Kiru	-2.05		-0.70	0.68					
	Hayin Dogo	-2.14		-0.97	-0.77			-0.97		0.80
	Ikuzeh	-1.81		-0.91	-0.56	-0.53	0.41			-0.64

Only variables with significant effects shown ($p < 0.10$)

factors correlate with a combination of village dummies and household characteristics, but levels of explained variation are low.

2.4.3 Relating heterogeneity in production attitudes to efficiency levels

We use the DEA methodology as described in Section 2.3.3 to compute different scores for technical, food, profit and food allocative efficiency. An estimate of profit allocative inefficiency is determined as well using the additive decomposition described in Section 2.2. Table 2.7 shows the averages of inefficiency levels estimated, whereby a farm is considered efficient when the score takes the value of 0, and inefficient for scores greater than 0. The measure of profit allocative inefficiency denotes the amount of profit lost, divided by the initial cost level, due to allocative inefficiency. Hereby, smaller values also reflect higher levels of profit allocative efficiency.

Table 2.7: Inefficiency levels

Efficiency measure	Technical (Input Oriented)	Food	Food allocative	Profit	Profit allocative
Mean	0.33	0.34	0.15	0.85	82
Standard Deviation	0.34	0.25	0.15	0.20	154

Inefficiency levels are expressed on a scale between 0 and 1 (0 = full efficiency). The estimate of profit allocative inefficiency is based on the additive decomposition in equation (2.10).

The results show that, on average, farmers are relatively food allocative efficient, but far from profit efficient, which seems to confirm the high scores on staple food production and low scores on gross margins obtained in the ranking. Total food inefficiency, combining both output-oriented technical and allocative inefficiency, averages 0.34. A large part of the latter inefficiency is attributable to technical inefficiency. The average (input-oriented) technical inefficiency level is 0.33. This is relatively low but combined with the standard deviation of 0.34, still implies that a considerable group of farmers produce at very low efficiency levels. Furthermore, profit inefficiency levels are high, i.e., production and consumption decisions are clearly not separable, but do show some variation across the sample. Profit and food efficiency are correlated at 0.19 (significant at 5%). This is contrary to the discussion in Section 2.2, in which a negative correlation was expected. It thus suggests that both objectives do not directly imply a trade-off to most farmers.

Table 2.8 shows the results of estimating equation (2.24) for the different efficiency measures[1]. In all these estimations significant effects of some behavioural factors are observed. Especially the factors describing risk averting behaviour and the minimization of labour use are highly significant in multiple estimations.

We formally test whether the inclusion of the behavioural factors does give a better explanation of the variation observed. In all three final models an F-test on the exclusion of the behavioural factors is rejected. Moreover the pseudo-R^2, adjusted-R^2 and Akaike's information criterion (AIC) indicate a better fit after including behavioural factors in all estimations (bottom rows Table 2.8). On the other hand, the drop in AIC, indicating an improvement in fit is only moderate but significant.

The direct effects of the socio-economic variables included are similar to those described in other efficiency studies in African smallholder agriculture. Technical efficiency levels increase with soil quality, average age in the household and –after correcting for its endogeneity– with use of hired labour. There is a negative effect of schooling on technical efficiency levels, possibly due to an orientation for, and interest in the non-farm sector. Farmers for whom the distance to farms is larger, are less food allocatively efficient. This possibly reflects that riverbed fields, used for production of high-value crops, are commonly not found close to households due to risk of flooding. Furthermore, profit (food) efficiency increases (decreases) with other sources of income and increases (decreases) if farmers have received agricultural training. A number of other variables are dropped from the final models as no significant effects are found. The village dummies are included to pick up both local climatic conditions, and the fact that not all crops can be cultivated in each location.

Five of the nine identified factors do affect efficiency levels, although the significant effects of factor 8 disappear after correcting for endogeneity (regression B). The signs of the parameter estimates largely confirm intuition. Factor 3 strongly relates to the desire to minimize labour use (from the pair-wise ranking) and negatively affects technical efficiency levels. Factor 1, resulting from questions expressing issues related to risk aversion, decreases (increases) levels of profit (food) allocative efficiency. This coincides with the commonly expected effects of risk aversion. Factor 6 expresses a strong subsistence orientation, and farmers scoring high on this factor display lower levels of profit efficiency. The effect of factor 5 –relating

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[1] Using Stata 9.2. With the exception of profit allocative inefficiency (Model D), the dependent variables are a measure of efficiency, whereby higher values reflect higher levels of efficiency.

Table 2.8: Relating variation in efficiency levels to characteristics and behaviour

	Regression	**A**	**B**	**C**	**D**
	Efficiency Measure:	Technical Efficiency	Technical Efficiency[2]	Food allocative	Profit allocative[3]
	Estimation method:	Tobit	IV-Tobit	Tobit	OLS
Socio-economic variables	**Exogenous Variable[1]:**				
	Farm size				
	Farm distance			-0.05***	
	Farm quality		0.35***		
	Household size				
	Other income source of household head (Dummy)			-0.08***	0.50***
	Average age household		0.14*		
	Achieved primary/koranic education(Dummy)	-0.24**	-0.13*		
	Achieved secondary/tertiary education (Dummy)	-0.22*	-0.24**		
	Distance to markets	0.16**			
	Total value of assets				0.17***
	Total livestock ownership (TLU)				
	Household has attended agricultural trainings (Dummy)			-0.13**	
	Household head engages in wage labour (Dummy)			-0.09***	
	Household head hires wage labour (Dummy)	-0.26**	0.44**		
Village Dummies	Bindawa				
	Kunchi				
	Warawa			0.13	-0.59**
	Kiru	0.47***		0.08	0.50**
	Hayin Dogo	0.41***	0.22***		
	Ikuzeh	0.19*	0.12*		-1.28***
Behavioural factors	Factor 1 Risk averting behaviour			0.02**	-0.28***
	Factor 3 Minimize labour use, cannot invest in soils	-0.13***	-0.08***		
	Factor 5 Wants to be a successful farmer in the future			-0.03*	-0.15**
	Factor 6 Subsistence crop production is a duty				-0.13*
	Factor 8 Maximizing financial benefits from farming	-0.09**			
	F-test on excluding behavioural factors (p-value)	0.00	0.00	0.05	0.00
	Wald test exogeneity[4]	0.99		0.98	0.61[5]
	With behavioural factors Pseudo -R^2	0.30		2.41	0.38[6]
	With behavioural factors AIC	185.64	89.60	3.96	413.25
	Without behavioural factors Pseudo -R^2	0.27		1.38	0.34[6]
	Without behavioural factors AIC	197.68	115.91	12.55	444.54

[1] * significant at 10%, ** significant at 5%, *** significant at 1%, only significant variables shown

[2] Tobit regression in which use of hired labour is instrumented for by total value of assets

[3] Dependent variable is log of profits lost due to allocative inefficiency multiplied by -1. Higher values reflect lower losses and higher levels of profit efficiency.

[4] p-value of a Wald-test on exogeneity is shown. The behavioural factors, use of hired labour, and engagement in wage labour are instrumented by using Newey's two-step estimator.

[5] Durbin-Wu-Hausman test

[6] Adjusted-R^2

to the desire of being a successful farmer– is somewhat puzzling as it leads to lower levels of food and profit efficiency.

We finally analyse whether the endogeneity of the behavioural factors affects the consistency of the estimation, by using a Wald-test on exogeneity. This analysis is however hindered by the availability of instruments. In regression A two behavioural factors appear significant, for which potential instruments are needed. Of the three village dummies not affecting technical efficiency levels, two strongly correlate with both behavioural factors (Table 2.9).

Table 2.9: Identifying instruments

	Household hires wage labour	Household engages in wage labour	Factor 1	Factor 3	Factor 5	Factor 6	Factor 8
Household Size					0.25*		
Age household head						0.41	
Total value of assets	0.07***	-0.09***					
Livestock ownership					-0.13**		
Kunchi (Village dummy)			-0.61***	1.61***			0.63***
Warawa (Village dummy)				0.99***			-0.50***
Hayin Dogo (Village dummy)			-1.01***				
Ikuzeh (Village dummy)					-0.66***		
F-value	19.29	16.55	19.17	60.89	4.55	3.20	10.23

** significant at 5%, *** significant at 1%
Table shows reduced form estimations, explaining potential endogenous variables (top row) from exogenous variables not affecting efficiency levels.

Furthermore, use of hired labour is likely to suffer from reverse causality. First, farmers operating at low efficiency levels may benefit more from hiring labor thereby increasing the demand for it. Second, decisions on using additional hired labor may be influenced by favorable weather outcomes. A potential instrument for the latter is the total value of assets, which does not correlate to technical efficiency levels. Similarly, suitable instruments are identified for the behavioural factors with significant effects in regressions C and D, as well as engagement in wage labour. The identified instruments are shown in Table 2.9. Unfortunately the reduced form estimations for the factors 5 and 6 do not pass the rule-of-thumb for a strong instrument, as the F-value is smaller than 10 (Stock and Watson, 2003).

Subsequently, a test was carried out to examine whether the inclusion of behavioural variables z_j induces endogeneity bias in regressions A, C and D. The results of a Wald-test[2] –under the null hypothesis of exogeneity– using Newey's two-step estimator, does not lead to rejecting the null hypothesis in all cases (bottom rows Table 2.8). Unfortunately the likelihood function does not converge for the case in which all endogenous regressors are instrumented simultaneously. Nevertheless, the negative effect of hired labour in regression A is suspect, since the causal effect of using hired labour on efficiency levels is expected to be positive. We therefore carried out a separate regression in which only hired labour is instrumented. This led to a rejection of exogeneity of this parameter ($p=0.03$), for which we instrument (regression B). It shows that the partial effect of hired labour on technical efficiency levels is indeed positive as expected. Since none of the tests reject the exogeneity of the behavioural factors z_j, we conclude that including them does not affect the consistency of estimating (23).

2.5 Discussion and Conclusion

This chapter makes a contribution to the unbundling of personal goals and preferences and farm productivity in rural areas of Sub-Saharan Africa. To this effect we relate heterogeneity in farmer production goals and preferences to allocative and technical efficiency levels.

A number of other studies have related farm efficiency levels to household characteristics, thereby assuming such variables fully explain differences in personal goals and preferences. Our results suggest however that the inclusion of both household characteristics and farmer goals and preferences, i.e., behavioural variables, gives an improved explanation of observed differences in allocative and technical efficiency levels. Furthermore, since only part of the variation in behavioural variables is explained from household characteristics, omitting farmer goals and attitudes from an efficiency analysis is likely to induce some degree of omitted variable bias. On the other hand, the goodness-of-fit measures suggest though that the level of additional variation explained is moderate, and the total bias due to omitted behavioural factors is not likely to be very large.

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[2] A Durbin-Wu-Hausman test was used in the OLS regression D.

Unfortunately, since many household and regional characteristics correlate both with behavioural factors and efficiency levels, the identification of variables to instrument for the potentially endogenous behavioural variables is complicated. Nevertheless, the Wald tests on exogeneity of the behavioural variables are not rejected.

In the analysis presented we compare three different measures of efficiency: technical efficiency, profit allocative and food allocative efficiency. The two allocative efficiency measures used, are included as two extreme cases between which farmers operate: participation in all or exclusion from all markets. The results from both efficiency measures suggest that most farmers are relatively food efficient and only few are profit efficient. Hence household separability holds only for a small number of farms. This is similar to Carter and Yao (2002) who found that separability holds for only 20% of their sample in rural China. Furthermore we find that non-separability not only results from household characteristics directly, but also from personal goals and preferences. A few behavioural factors stand out.

First, levels of risk aversion do not affect technical efficiency levels, but do affect food allocative profit allocative efficiency. For example, the analysis of profit allocative efficiency shows that households with relatively high asset ownership display higher levels of profit efficiency. Levels of profit efficiency are, however, lower for households facing higher levels of risk aversion, conditional on the asset level. Furthermore we do not find a strong relationship between level of assets and levels of risk aversion (similar to e.g., Binswanger, 1980). Our reduced form estimations do show that risk aversion levels in a household mainly depend on the location of the household, whereby risk aversion increases for decreasing levels of rainfall.

A second effect is found from the factor indicating the need to fulfil subsistence food demands from own production, which lowers levels of profit allocative efficiency. This behavioural factor is strongest in the most isolated location, contrary to a location close to the major urban centre, Kano. Apart from age, no household characteristics appear to relate to this factor, and the total observed variation remains largely unexplained from the variables included. Local believes and personal perceptions, such as status and pride, might further explain this finding.

Finally, a factor expressing a desire of being a successful farmer explains both food and profit allocative efficiency negatively. This is a somewhat puzzling effect and possibly farmers, for whom this view is strongest, aim for an objective other than food production or profits.

The observed effects on technical efficiency are similar to other studies. Farm quality strongly explains higher levels of technical efficiency, as documented elsewhere (e.g., Sherlund *et al.,* 2002). Furthermore the goal to minimize labour use negatively affects technical efficiency levels. Similarly, in Chapter 4 we observe in the same region that the land to labour ratio explains differences in technical efficiency of sorghum production, after correcting for heterogeneity in soil fertility.

We are not aware of any studies that quantify heterogeneity in farm attitudes in SSA, neither of any studies incorporating such attitudes in an agricultural productivity analysis, while similar studies in a developing country setting are sparse. Solano *et al.* (2006) did relate farm-decision-making profiles to performance of smallholder farms in Costa Rica. While they did not quantify the relationship between a farmers' environment to his goals and attitudes, they do find an indirect relationship between decision-making profiles, which affect management indicators, which in turn affected various farm performance indicators. Contrary to our results, however, they did not find a direct relationship between technical efficiency levels and farmer goals.

Given the significant effects found on efficiency levels in our study, those by Costa and Rehman (1998) and Solano (2006), as well as the growing body of research describing the presence of heterogeneity in decision-making profiles in developed countries (e.g., Ondersteijn *et al.* 2003; 2006; Basarir and Gillespie, 2006; Hanson, 2007), it clearly deserves more attention in farm-level research in developing countries. However, the approach followed in this research raises some additional issues.

First, the large number of factors identified suggests that a complex combination of factors describes the different nuances of attitudes, goals and preferences observed. Only a limited amount of variation in attitudes can actually be explained from the data on farmers' background. This could be related to problems in data collection, but we feel is unlikely as the methodology was pre-tested extensively in non-sample areas. As a result the questions and fuzzy pair-wise ranking were such that as little information would be lost in translation. Furthermore, it could be that the scale used for the questions is too small to capture all nuances. On the other hand it is doubtful if it would have been possible capturing more refined nuances of low-educated farmers with a more elaborate scale.

Even though only four of the identified behavioural variables actually correlate with efficiency levels, it makes the design of empirical surveys, aimed at replicating similar research in other areas, difficult. While behavioural differences in labour use and risk aversion are known to affect production decisions, we are not aware of other studies documenting the productivity effects of, for example, the degree of subsistence orientation of a farmer. Therefore further research by economists and other social scientists should determine whether the goals identified in this research, indeed describe the minimum relevant set for productivity analysis.

Chapter 3

Heterogeneity in farmers’ production decisions and its impact on soil nutrient dynamics: Results and implications from northern Nigeria[*].

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[*] This chapter is under review as:
Berkhout, E.D., Coulibaly, O., Schipper, R.A., Van Keulen, H. Heterogeneity in farmers’ production decisions and its impact on soil nutrient dynamics: Results and implications from Northern Nigeria. Submitted.

Abstract

Sustainable use (in terms of nutrients) of soil resources by farmers in Sub-Saharan Africa is constrained by institutions and markets. This chapter explores the case of Northern Nigeria through a recent approach, using a combination of multi-objective programming, multi-attribute utility theory and bioeconomic modelling. We find that farmers with larger land holdings place more emphasis on gross margins and sustainability. Contrary to other bioeconomic studies in similar regions, we find positive nutrient balances for some of these market-oriented farmers. Risk aversion, operationalised through variance minimization, appears an important attribute in this study for many farm households with smaller land holdings. Subsistence production of cereals is dominant in such farm plans that lead to negative soil nutrient balances, especially for potassium. This could potentially be alleviated by adoption of well-designed technologies for forage production, residue and manure management. Farmers who place a large importance on gross margins in their utility function are likely to benefit most from policies aimed at enhancing profitability through improving the functioning of markets. The large group of risk averse farmers will have the largest immediate gain in utility from policies and technologies aimed at lowering production risk in high-value crops. Additional policies aimed at creating a stronger market–oriented production by the least-endowed farm households could play a role in reducing intensity of soil fertility mining. Under these conditions, the efficient cropping pattern shifts (partially) from cereal cropping to high value crops, associated with higher input use. The approach followed allowed us to identify heterogeneity in production strategies and to quantify differences in the use of soil nutrient resources. While the obtained results are similar to those of other studies, they appear sensitive to the type of cropping activities included in the analysis, and additional methodological research is required. Extensions of the used method should further account for temporal and spatial differences in soil fertility, leading to differences in nutrient uptake and production, as well as potential temporal heterogeneity in production strategies.

3.1 Introduction

Population and income growth in the savannah regions of West and Central Africa (WCA) lead to an increase in the demand for food products, a decline in the available arable land and reduced length or absence of fallow periods, while soil fertility steadily declines (e.g., Giller *et al.*, 2006). The latter results in a decrease in nutrient holding capacity of the soil profile, deterioration of the soil surface structure and a reduction in infiltration capacity. This process leads to declining yields, and a likely increased occurrence of pests and diseases.

Hence, soil nutrient mining, i.e., the gradual decline in soil fertility, is considered one of the most important constraints towards increasing agricultural production in many parts of Sub-Saharan Africa (SSA) and the Savannah regions of WCA in particular (e.g., Heerink *et al.*, 2001b; Sanginga *et al.*, 2003). Agricultural research has focused therefore on development of improved farming systems for the Savannah regions with special emphasis on maintenance of and/or improvement in the quality of the soil resource base.

Results of recent studies suggest that sustainable use of soil resources in agriculture in many areas of SSA cannot realistically be achieved without institutional changes and improvements in the functioning of markets (e.g., Savadogo, 2000; Ruben *et al.*, 2001; Stroosnijder and Van Rheenen, 2001; Lee *et al.*, 2006; Woelcke, 2006). The results of Woelcke (2006) in analyzing the impact of improved farming systems in a bio-economic model, suggest that positive nutrient balances for smallholders in Uganda are economically infeasible without policy changes.

To tackle interdisciplinary problems of sustainable use of soil resources in agricultural production, so-called bio-economic models have been applied widely. Such models, basically integrating economic farm household models (FHMs) (Schweigman, 1985; Singh *et al.*, 1986) and biophysical models from agronomy and soil sciences (e.g., van Keulen and Wolf, 1986), are powerful tools for simulating farming in its complex environment, and can therefore be used for *ex ante* assessment of new technologies and policies.

Bio-economic models have been applied in various regions (see Heerink *et al.*, 2001a). A FHM forms the decision structure in most applications (e.g., Sissoko, 1998; Kruseman, 2000; Shiferaw *et al.*, 2001; La Rovere *et al.*, 2005), but some use decision rules (Struif Bontkes, 1999) or are village-level applications (Barbier, 1998). All applications focus on nutrient depletion, some extended with soil erosion, where a (dynamic) nutrient balance describes soil nutrient dynamics (e.g., Shiferaw *et al.*, 2001). The underlying concept in these applications is to incorporate the rate of soil nutrient mining into an economic decision-making framework, which then becomes a decision variable.

Farm households and farming systems in SSA are characterized by a high degree of heterogeneity in livelihood capital and strategies (e.g., Ellis, 2000). Social differences in wealth, source of income, endowments and/or status, or, more general differences in livelihood strategies, as well as production potential, population pressure and market access further differentiate farm households. These typological differences, or differences in assets, may have a large effect on the household priorities, while livelihood strategies may even be different for farm households with equal livelihood capital. Hence, preferences attached to important production criteria (attributes) such as gross margin, are likely to differ. Consequently, heterogeneity in the decision-making structure of farm households is the rule rather than the exception, and the degree of soil nutrient mining/replenishment is likely to vary among farm households. Therefore, potential heterogeneity in production attributes amongst farm households should be included in a bio-economic model. Janssen and Van Ittersum (2007) equally stress the need to better reflect actual farmer decision-making in bio-economic models.

Romero and Rehman (2003) provide an overview of the extensive use of multiple production attributes in Mathematical Programming-based FHMs. Nevertheless, only a limited number of bio-economic studies used a multi-criteria approach (e.g., Barbier, 1998; Kruseman, 2000; Savadogo, 2000; Laborte, 2006). In most of these studies, homogeneity in preferences for multiple attributes was assumed for different farm typologies.

Evidently, some production strategies are less detrimental to the quality of the soil resource base than others. Hence, by identifying reasons why “better” (i.e., more sustainable) production strategies are selected by certain types of farm households, better policies and technologies to achieve sustainable use of soils in SSA can be designed and advocated.

To examine whether heterogeneity in preferences for production attributes among farm households exists and whether that makes a difference in terms of the use of soil resources, we follow a four-step approach. Firstly, we construct a bio-economic simulation model linking soil nutrient balances to household production decisions in the region of study.

Secondly, we are interested in determining the effects of various production attributes on soil resource use. We therefore identify feasible Pareto-efficient production sets for representative farm households in different locations by using Multi-Objective Programming (MOP) (e.g., Ballestero and Romero, 1998). Pareto-efficient sets are defined as feasible combinations of two or more attributes, such that it is not possible to improve any of the attributes without negatively affecting (an)other(s). Hence, these efficient combinations define trade-offs between attributes and for this purpose we defined a number of attributes that are likely to play an important role in farm households.

Thirdly, we are interested in determining which production attributes are considered important by farm households, and how they differ across households. We therefore use the Pareto-efficient set, in combination with observed cropping patterns at farm level to identify preferences, through normalized weights, for different production attributes for each individual farm household. For this process we use Multi-Attribute Utility Theory, based on the approach proposed by Gomez-Limon *et al.* (2003; 2004).

Finally, cluster analysis (e.g., Hair *et al.*, 1995) is used to group farm households based on their respective weights, to obtain insights in possible underlying factors explaining differences in weights, and to analyse how these differences affect soil resource use.

We use this approach to analyse heterogeneity in production decisions and their impact on soil resource use in the Savannas of Northern Nigeria, a region characterized by strong land use intensification, reduced fallowing and associated problems of soil fertility decline, while at the same time it is a major food production region in West-Africa (e.g., Okike *et al.*, 2001).

In the next section we review literature using multiple attributes in bio-economic studies. Section 3.3 describes the applied methodology, Section 3.4 elaborates on the data and location, Section 3.5 presents the results and Section 3.6 discusses and concludes.

3.2 The use of multiple attributes in bio-economic models

Farm households in SSA may have several, sometimes conflicting, production objectives or attributes. Among other things, liquidity requirements, desire for leisure time, risk aversion, food subsistence requirements and consumption preferences may play important roles. To incorporate these different objectives or attributes in the analysis, a number of variations on classic farm household models have been proposed. Schweigman (1985), Hazell and Norton (1986) and Singh and Janakiram (1986) simultaneously introduced the basis for most farm household models used today. The latter discussed household models from an econometric perspective, while the former two focused on mathematical programming approaches. The common structure is a constraint set, based on land, labour and capital availability, and an activity set, combined with a utility function based on expected income or gross margin. Singh and Janakiram (1986) included leisure as a component in the utility function, to account for farmers' desire of using minimum amounts of labour to achieve certain income levels.

Approaches to incorporate risk in a FHM usually start from the expected utility criterion, maximizing the expected value of a utility function, whereby a personal risk attitude is included in the utility function (e.g., Hardaker *et al.*, 1997). This is the most frequently used approach in analyzing soil fertility problems in SSA (e.g., Kruseman, 2000; Deybe, 2001). Another approach is to consider the first two moments of the Taylor approximation, i.e., expected value (E) and variance (V) of gross margins. This leads to the class of E-V programming approaches, such as the (target-) MOTAD method (Hazell, 1979; Tauer, 1983), that Barbier (1998) used in simulating soil resource use at aggregated village level. Nevertheless this approach still requires assumptions on the levels of risk aversion present.

Subsistence consumption requirements are frequently incorporated as inflexible constraints, and a utility function composed of attributes other than food production is optimized. This is referred to as the optimization of lexicographic utility, or the maximization of free disposable income (e.g., Laborte, 2006; Woelcke, 2006). It is thereby assumed that a farm household always aims at meeting its food subsistence demands first, either through own production or market purchases, and subsequently optimizes other attributes such as gross margin.

Frequently, the importance of multiple attributes is hypothesized, but the exact decision structure is unknown. To avoid making assumptions on their relative importance, researchers have used Multi-Objective Programming (MOP). MOP is then used to determine a pay-off matrix, consisting of ideal (best) and anti-ideal (worst) outcomes of various attributes and Pareto-efficient production sets, i.e., sets with feasible production points whereby it is not possible to improve any of the attributes without negatively affecting (an)other(s). The advantage is that it allows the determination of trade-offs between attributes, without making *a priori* assumptions on the preferences of the farm household.

Stroosnijder and Van Rheenen (2001) document the development of a MOP to determine a pay-off matrix in a village in Burkina Faso, with gross margins, crop production, livestock production, erosion and nitrogen losses as attributes. Based on this work, Van Paassen (2004) implemented a co-learning approach to guide discussion between policy makers and farmers on strategies to accomplish sustainable use of soil resources.

Maatman (1999), analysing subsistence farmers in Burkina Faso, follows a different approach in which a multi-objective function is optimised. This function consists of the minimization of nutrient deficits during the dry season and the subsequent harvest period, minimization of subsistence cereal requirements and the maximization of revenues from sales. Deficit in this model is defined as the largest deficit under different potential weather outcomes. Furthermore, weights in the objective function can represent different levels of preferences for a farmer under study.

In this study, we are interested in determining both the effects of various production attributes on soil resource use, and the production attributes considered important by farm households. Gomez-Limon *et al.* (2003, 2004) proposed the use of Multi-Attribute Utility Theory (MAUT) for the latter purpose for farmers in Spain, considering gross margin, variance, labour and water use as attributes. MAUT has been used in various instances in agricultural research to elicit preferences for various, sometimes conflicting, attributes (e.g., Hardaker *et al*., 1997; Van Calkar *et al*., 2005; 2006).

In this chapter we follow the approach used by Gomez-Limon *et al.* (2003; 2004) who assume that each farm household maximizes a linear additive utility function of a household-specific combination of attributes. This concept is theoretically attractive and allows determining farm household-specific weights for the various attributes, by using simulation results and observed cropping patterns. However, its practical application is hampered by 1) the necessity of mutual utility independence among the attributes, and 2) the requirement for the weights used in the Multi-Attribute Utility Function (MAUF) to sum up to one (e.g., Ballestero and Romero, 1998). While the utility independence requirement is difficult to ascertain in practice, Huirne and Hardaker (1998) found the results from a MAUT analysis, assuming utility independence, to be close to true decisions. Hence, they suggest that the error is likely to be small when the independence assumption is not fully met.

3.3 Methodology

In this chapter we apply a combination of MOP and MAUT to examine the effects of heterogeneity in production strategies on soil resource use by rural farm households in Nigeria. By using MOP we obtain valuable information on trade-offs between soil resource use and production attributes, while subsequent application of MAUT allows determination of farm household-specific preferences for each of the attributes, thus identifying farm households that are more sustainable than others due to heterogeneity in production preferences. Finally, we group farm households with relatively similar preferences by using cluster techniques and discuss the resulting soil resource use of the various groups.

While this allows us to determine the parameters in the utility function for each farm household, a drawback remains that there is little flexibility in the decision structure itself. While it might be appropriate to assume a lexicographical utility structure for some farm households, to satisfy subsistence needs first, this may not be the case for others. Unfortunately, no solution is readily available to overcome this problem and we include subsistence needs as a constraint for all households, which should be met through either farm production or market purchases. In the remainder of this section we describe the details of the modelling approach, while we discuss the data sources in Section 3.4.

3.3.1 Bio-economic model description

A farm household model, including a soil nutrient balance, forms the base of the analysis. The decision variables reflect the farm area devoted to each of the included land use options, as well as total production of each of the crops. Other decision variables include monthly decisions on consumption; purchases of inputs; sales of harvested products; contracting small loans; hiring of labour; and/or engaging in agricultural wage labour on other farms.

The constraint set is chosen such that it accurately reflects the real-life constraints faced by the farm household. The main constraints limit the use of land, labour and capital. The total area devoted to the land use options should not exceed farm size, which is subdivided into two land types, upland fields and fadama fields. Fadama fields are situated in riverbeds, thus characterized by high moisture availability, and provide ideal conditions for cultivating crops such as sugarcane and rice.

The sum of labour requirements for the selected land use options each month should not exceed total household labour supply, including hired labour, minus labour devoted to off-farm activities. Household members can engage in off-farm agricultural wage labour, available in the region. Labour spent on off-farm agricultural wage labour is limited to 10% of the monthly available labour, to reflect labour market imperfections.

A capital balance keeps track of the monthly capital status. Revenues from sales of crops and wage labour are added, and expenditures on agricultural inputs, such as fertilizer and hired labour, as well as expenditures on market-purchased goods for consumption are subtracted. Based on information from key informants in the locations surveyed, a small and limited informal capital market was included, creating the possibility of contracting small loans, while no formal credit facilities are present in the area of study. Finally, the minimum food requirements of the family in the target year, the period between two successive harvest periods, should be met either through domestic produce; market-purchased goods, at a higher price reflecting transaction costs; or a combination of both.

Balance equations keep track of the annual changes in nitrogen (N), phosphorus (P) and potassium (K) stocks, in dependence of the production plan, as described in Equation (33) (Appendix B). For calculating this attribute we use the method as described by FAO (2004b). We include loss of nutrients through erosion

(sne_s) and deposition by wind and rain (snd_s) as parameters, assuming that these are not influenced by the farm household. The other components, dependent on the production plan and thus under the influence of the farm household are: nutrients added through inorganic fertilizers (NAF_s); biologically fixed nitrogen by legumes (BNF_s); gaseous losses from applied fertilizer (NLG_s); and nutrients removed in harvested product (NLH_s). Unfortunately, no detailed information on quantities of manure applied was available. We did not include manure in the nutrient balance, but we analysed total fodder production in order to obtain an upper limit on potential manure production.

3.3.2 Simulation approach – Multi-Objective Programming

The computational requirements of the MOP-model are large and therefore an approximation procedure was followed. Each attribute is parameterised over the interval delimited by its ideal and anti-ideal values. All other attributes are then optimised individually, which generates a number of curves based upon this interval. Finally the convex envelope described by the points is selected. This envelope contains feasible production points, based on the properties of linear programming, and represents a close approximation of the Pareto-efficient set. To determine trade-offs between attributes, we calculate these sets for an average resource-poor household in each location, which is identified by clustering farmers with the main resources as cluster variables. Although the Pareto-efficient sets are different for other farm(er) types, the trade-offs, in which we are interested at this point, are largely similar.

Based on the studies described in Section 3.2, we have selected four commonly used attributes: (1) gross margin, calculated as the difference between the value of harvested products and costs (fertilizers; pesticides; hired human labour; hired animal labour). This attribute intends to capture the farm households' needs and preferences for financial resources; (2) variance, computed as the total variance of the expected market value of the production plan. This attribute captures varying degrees of risk aversion among farm households; (3) N-balance, defined as the loss of N from the farm, as explained in more detail above. Many studies included this attribute to model trade-offs between sustainability with regard to this attribute and other production attributes. For farm households that are more concerned with maintaining soil resources for future generations, it may be an important attribute. The definition of the N-balance as the main criterion for sustainability arguably does not capture all aspects of sustainable use of soil resources, though is chosen to keep the analysis in this stage as simple as possible; (4) total labour use as the total use of labour on the farm, including hired labour. Equations (31) to (34) (Appendix B) give the mathematical notations of the attributes introduced. All four objectives were defined in a maximization context; hence, the variance and the N-balance were multiplied by -1 to reflect the minimization structure. In the remainder we refer to the attributes defined by Equations (31), (32), (33) and (34) (Appendix B) as Gross Margin (*GMN*), Variance (*VAR*), Sustainability (*SUS*) and Labour (*LAB*), respectively.

3.3.3 Simulation approach – Multi-Attribute Utility Theory

In the second step, we estimate farm households' individual utility functions by using Multi-Attribute Utility Theory (MAUT). We assume that for each individual farm household, the utility function is an additive function of the multiple attributes L defined by Equations (1).

The Multi-Attribute Utility Function (MAUF) that a farm household $k \in K$ intends to maximize, is described by Equation (3.1). The preference towards attribute $l \in L$ is described by its normalized weight w_{kl} , with $w_{kl} \in [0,1]$. Moreover, $f_l (X)$ denotes the partial utility attained for attribute l under farm plan X. When $w_{kl} = 0$, attribute l has no importance to farm household k, when $w_{kl} = 1$, attribute l is the only important attribute to farm household k. When a farm household k exclusively considers production attribute l important, its associated cropping choice and production plan is X_{kl}, in which the area of the farm devoted to crop i is x_{ikl}. This production plan defines one of the extreme points of the Pareto-efficient set, already generated with Multiple-Objective Programming. In the same way, all associated cropping patterns of the extreme points X_{kl} were determined in the first step.

The observed farm plan for farm household k is X^*_k, with allocation coefficients to crops x^*_{ik}. Following Gomez-Limon *et al.* (2003; 2004), we assume that the observed production plan is a linear combination of the extreme points of the Pareto-efficient set as given in Equation (3.2). By solving the LP-program in Equations (3.3) - (3.5) we obtain the weights, w_{kl}, in the MAUF of each farm household.

$$U_k = \sum_{l \in L} w_{k,l} * f_j(X^*) \qquad \forall k = 1, .., K \quad (3.1)$$

$$X_k^* = \sum_{l \in L} w_{k,l} * X_{k,l} \qquad \forall k = 1, .., K \quad (3.2)$$

$$\min \sum_{i,k \in I,K} d_{i,k}^+ + d_{i,k}^- \qquad (3.3)$$

$$\sum_{l \in L} w_{k,l} * x_{i,k,l} + d_{i,k}^+ - d_{i,k}^- = x_{i,k}^* \qquad \forall k = 1, .., K \quad (3.4)$$

$$\sum_{l \in L} w_{k,l} = 1 \qquad \forall k = 1, .., K \quad (3.5)$$

3.3.4 Statistical Analysis

Finally, we compute pair-wise correlations between the weights calculated and various socio-economic variables. Subsequently we group farm households with similar weights on the basis of cluster analysis. We use non-hierarchical clustering to determine the appropriate number of clusters, and then use the cluster centres as seeds in a k-mean non-hierarchical clustering method (Hair *et al.*, 1995). As a final step, we construct the MAUF for an average farm household from each cluster, to identify utility-efficient production plans and soil nutrient balances.

3.4 Data and setting

We apply the above approach to three villages in the Northern Guinea Savannah of Nigeria (Table 3.1), Ikuzeh (Kajuru Local Government), Hayin Dogo (Giwa Local Government) and Danayamaka (Maikarfi Local Government), all in Kaduna State. These locations are selected because of data availability from participatory agronomic trials, carried out for a number of years by the International Institute of Tropical Agriculture (IITA).

The physical environment is characterised by one rainy season, from May till October with average annual rainfall of about 1200 mm in Ikuzeh and 1000 mm in the other two villages. A baseline survey (IITA, 2002), comprising 120 farm households, was carried out in 2001 to collect detailed production information and socio-economic characteristics. Available data include land use strategy; yields; input use; farm size; education level; household size; age of household head; livestock and asset ownership (Table 3.2).

Table 3.1: Selected characteristics of the villages

	Ikuzeh	*Hayin Dogo*	*Danayamaka*
Households (number)	102	82	unknown
Distance to main road (km)	10	5	4
Fallow (years)	3	0	0
Land use intensity	62 %	100 %	100 %
Population density (inhabitants per km^2)	NA	250-340	170-210
Classification[1]	Low population density Low market access (LPLM)	High population density High market access (HPHM)	Low population density High market access (LPHM)
Households included in MAUF-analysis[2]	35	29	32

Source: Vandeplas (2001), population density from IITA GIS-laboratory

[1] Based on the classification proposed by Okike et al. (2001)

[2] A total of 120 farmers were included in the baseline survey. Some farmers disregarded because of outliers or incomplete data

Table 3.2: Characteristics of the representative farm households

Location	*Unit*	*LPLM (Ikuzeh)*	*HPHM (Hayin Dogo)*	*LPHM (Danayamaka)*
Number of observations	#	40	40	40
Tropical Livestock Units (TLU) owned	#	0.52	0.55	1.26
Household size	#	6.17	6.42	5.21
The total stated value of assets	$	23	23	57
Total farm size	Ha	4.28	1.87	4.40
Total fadama farm size	Ha	0.45	0.00	1.04

None of the villages has its own market, but major markets are relatively close to Hayin Dogo and Danayamaka, while far from Ikuzeh. It is observed in the baseline survey that farm size tends to be smaller in Hayin Dogo than in Danayamaka and Ikuzeh, due to the higher population density in the former. Therefore, we classify Ikuzeh as Low Population, Low Market Access (LPLM), Hayin Dogo as High Population, High Market Access (HPHM) and Danayamaka as Low Population, High Market Access (LPHM), based on the classification Okike *et al.* (2001) propose.

Sixteen crops, commonly grown in the study region are included and a slightly larger number of land use types, including the option of using low or high fertilizer doses, and possibilities of intercropping. Not all included crops are grown in each village. Therefore, some crops do not figure in all scenarios. Fodder yields incorporated are derived from the grain-fodder ratios used by Savadogo (2000).

Detailed data on labour use; basic information on household consumption; data on the informal credit market; and data on the agricultural wage labour market were collected in 2005. Soil data collected in trials (Nwoke *et al.*, 2004), complemented with data from literature (FAO, 2004b), are used to determine the parameters in the nitrogen balance equation. Nutritional values of crops are taken from FAO (2006), while estimates on household energy and protein requirements are from FAO (2004a). Average market prices for each commodity for each month in 2001 were provided by the Kaduna Agricultural Development Program (KADP). We use different prices for sales and purchases of commodities, based on observed price differences between rural and urban markets, or, when available, between farm gate and rural markets from neighbouring Kano State. The differences are small for the major grain crops, with urban market prices 2% higher than rural markets, and up to 40% for vegetables and other high-value crops.

3.5. Results and Discussion

3.5.1 Determining Pareto-efficient sets

The simulation results in the first step (Table 3.3) show that for different production attributes, cereal production constitutes the major part of all farm plans in the LPLM-domain, while high-value crops only play a marginal role in most farm plans. The exception occurs if labour is minimized; then okra, sugarcane and fonio are grown. The low labour requirements of fonio are confirmed in interviews, while sales of high-value crops allow purchase of additional staple foods in order to meet subsistence requirements.

In the LPHM and HPHM-domains, the Gross Margin- and Sustainability-efficient farm plans mainly consist of vegetables and legumes. Because vegetables have higher gross margins than other crops and receive higher amounts of fertilizer, while legumes fix nitrogen, these plans are more (N-) sustainable and yield higher monetary returns. Market-purchased cereal products meet subsistence requirements.

From these simulations we calculate pay-off matrices to quantify trade-offs between attributes and soil resource use (Table 3.4). The top row indicates the attribute that is being optimised, while the rows below give the resulting values of each attribute in the three locations.

The results indicate that in all three locations it is difficult to realize positive nitrogen balances (Table 3.4). Only for the Sustainability-efficient farm plans in the LPLM and HPHM-domains, and for the Labour-efficient farm plan in LPLM, positive values are calculated. Nitrogen balances are strongly negative in the LPHM domain,

Table 3.3: Efficient land use strategies under different production attributes for farmers in each village[1]

LandUse (Ha)	*LPLM (Ikuzeh)*[2]				*HPHM (Hayin Dogo)*[2]				*LPHM (Danayamaka)*[2]			
	GMN	SUS	VAR	LAB	GMN	SUS	VAR	LAB	GMN	SUS	VAR	LAB
Maize	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sorghum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rice	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maize-Cowpea relay					0.00	0.00	0.18					
Sorghum-Cowpea relay	3.59	0.00	1.82	0.00	0.00	0.00	0.64					
Late Millet	0.00	0.00	1.41	0.00	0.00	0.00	0.00	0.00	2.31	0.16	3.77	3.77
Hungry Rice/Fonio	0.00	3.06	0.10	3.10								
Cereals total[3]	**4.00**	**3.06**	**4.10**	**3.10**	**0.00**	**0.00**	**0.82**	**0.00**	**2.31**	**0.16**	**3.77**	**3.77**
Soybean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Groundnut	0.00	0.00	0.30	0.00	1.70	0.00	0.65	0.31	0.00	0.00	0.00	0.00
Cowpea					0.00	0.16	0.33	1.56	0.76	1.69	0.44	0.44
Legumes total[3]	**0.00**	**0.00**	**0.30**	**0.00**	**1.70**	**0.16**	**0.98**	**1.87**	**0.76**	**1.69**	**0.44**	**0.44**
Cocoyam	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00
Cassava	0.72	1.21	0.00	0.00								
Sweet Potatoes									0.00	0.00	0.00	0.00
Roots and Tubers total	**0.72**	**1.21**	**0.00**	**0.00**	**0.00**	**0.48**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Tomatoes					0.17	1.23	0.00	0.00	0.69	1.45	0.44	0.44
Hot Pepper	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.41	0.00	0.00
Okra	0.00	0.00	0.00	1.45					1.69	1.70	0.79	0.79
Sugarcane	0.00	0.45	0.32	0.17	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
High Value crops total	**0.00**	**0.45**	**0.32**	**1.62**	**0.17**	**1.23**	**0.07**	**0.00**	**2.37**	**3.58**	**1.23**	**1.23**

The table shows the resulting average farm plan in each location when each of the four different production attributes (top row) is optimised.

[1] *Since not all crops or crop-combinations are grown in each location, some rows are blank.*

[2] *Farm sizes are 4.73, 1.87 and 5.44 hectares for the LPLM, HPHM and LPHM-location respectively*

[3] *We grouped Maize-Cowpea relay and Sorghum-Cowpea relay systems under cereals. Therefore the cereals total shown is a slight overestimation (since it includes some cowpea), while the legumes total is a slight underestimation, since it excludes cowpea from these relays.*

Table 3.4: Pay-off matrix for all locations

		Optimization of:	*GMN (Gross Margin) (maximization)*	*SUS (Nitrogen Gain) (maximization)*	*VAR (Variance) (minimization)*	*LAB (Labour) (minimization)*
	Resulting values of:	Unit				
LPLM (Ikuzeh)	Gross Margin	$	**1388**	801	733	*555*
	Nitrogen Gain	Kg	-69	**47**	*-85*	24
	Standard Deviation	$	660	2764	**483**	*3034*
	Labour	Hrs	*3674*	2320	2780	**1289**
HPHM (Hayin Dogo)	Gross Margin	$	**1636**	959	1014	*944*
	Nitrogen Gain	Kg	*-84*	**45**	-39	-35
	Standard Deviation	$	349	*793*	**210**	285
	Labour	Hrs	1640	*8590*	907	**669**
LPHM (Danayamaka)	Gross Margin	$	**923**	*215*	895	895
	Nitrogen Gain	Kg	-229	**-58**	-340	-340
	Standard Deviation	$	1928	*2251*	**1161**	1161
	Labour	Hrs	22694	*46176*	15160	**15160**

*The table shows the results when each of the four attributes (top row) is optimised in each location of study. Ideal values (**bold**) represent the best possible outcome; anti-ideal values (italic) represent the worst possible outcome. All values are expressed as farm totals.*

where farms are large (Table 3.2). Farm plans for the Sustainability attribute in the HM-domains consist almost completely of vegetables and legumes (Table 3.3).

The pay-off matrix shows that Sustainability-efficient farm plans show positive N-balances in two of the three domains, and that in both these cases Gross Margins are better than, or similar to those for Variance- or Labour-efficient farm plans. In both the LPLM and LPHM domains, the Gross Margin-efficient plans are associated with negative N-balances, but less negative than for Variance-efficient plans. Thus, an increased household focus towards Gross Margin -though at the expense of increased variance- could be beneficial for sustainable soil resource use in these locations.

From the payoff matrices some important patterns emerge. First, in the two villages with higher market access, the Gross Margin- and Sustainability-efficient farm plans perform very poorly with regard to Variance and Labour, due to the shift to high-value crops. These crops are generally more labour-intensive and have more variable yields. Hence, while the Gross Margin and Sustainability farm plans are more sustainable with respect to soil resource use, they are unrealistic for strongly risk-averting farm households. Furthermore, the Sustainability-efficient production plans are unattractive with regard to the ideal value of Gross Margin, though comparable to Gross Margin in Variance-efficient farm plans in some domains.

Hence, a reduction in yield variability of crops grown in the Sustainability-efficient plans, for example through technology development, might persuade strongly risk-averting farmers to adopt more (N-) sustainable farm plans.

We further analyse the nutrient balances by determining ranges in annual soil nutrient balances. These ranges are defined by a lower bound, in which all fodder and (above-ground) plant residues are exported from the field, and an upper bound, in which they are left in the field. Figures 3.1, 3.2 and 3.3 show the results for N, P and K, respectively, for both the Gross Margin and Variance attributes.

Wide ranges, especially for the Variance-attribute, represent situations with cropping patterns consisting of crops associated with high fodder production, mainly cereals. The results show that the upper bounds are generally weakly negative or positive in a few cases. Recycling of fodder, through manure production, could technically -assuming zero-loss in manure production, storage and transport- provide nearly sustainable solutions. However, given the unavoidable and sometimes large losses in manure and/or compost production, storage transport and application (e.g., Rufino *et al.*, 2006), the figures make clear that additional inorganic fertilizer remains necessary to achieve sustainability in terms of soil fertility.

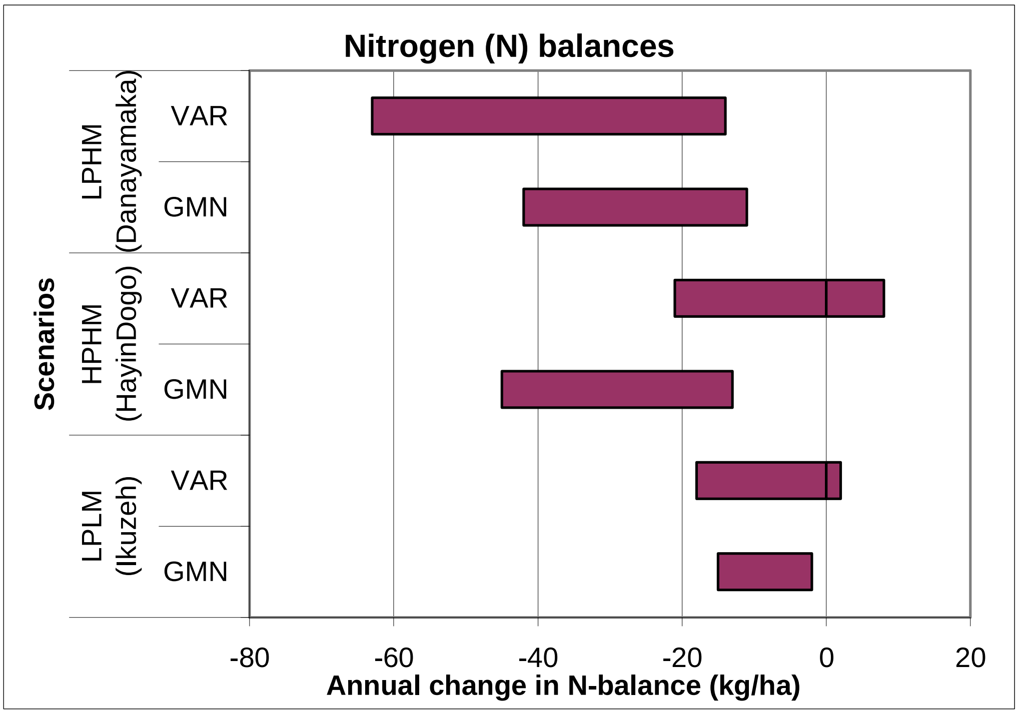

Figure 3.1: the range of the nitrogen (N) balances for maximization of gross margins and minimization of variance of the production plan. The lower bound represents the case in which all crop residues are removed from the field; the upper bound the case in which all crop residues are left in the field.

In both the LPLM and LPHM domain, the lower bounds of the balances for Gross Margin are higher, i.e., more sustainable, than those for Variance. Again this is due to the (partial) shift from cereals to high-value crops such as vegetables, and the associated higher input use, except for the HPHM-domain, where more legumes, with lower levels of fertilizer application, are chosen in the Gross Margin-efficient farm plan.

By using the Multi-Objective Programming approach described, Pareto-efficient sets are constructed in Figures 3.4 and 3.5. Since more than two objectives are assumed, it is not possible to graphically present the complete Pareto-efficient space. The figures therefore depict intersections of the Pareto-efficient object in hyperspace.

Figure 3.4, illustrating the trade-off between the Gross Margin and Sustainability attributes at the upper boundary, shows that in the LPHM domain, positive N-balances are infeasible. In the other two domains, some Pareto-efficient solutions are sustainable with regard to N-balances, as was already shown in Table 3.4.

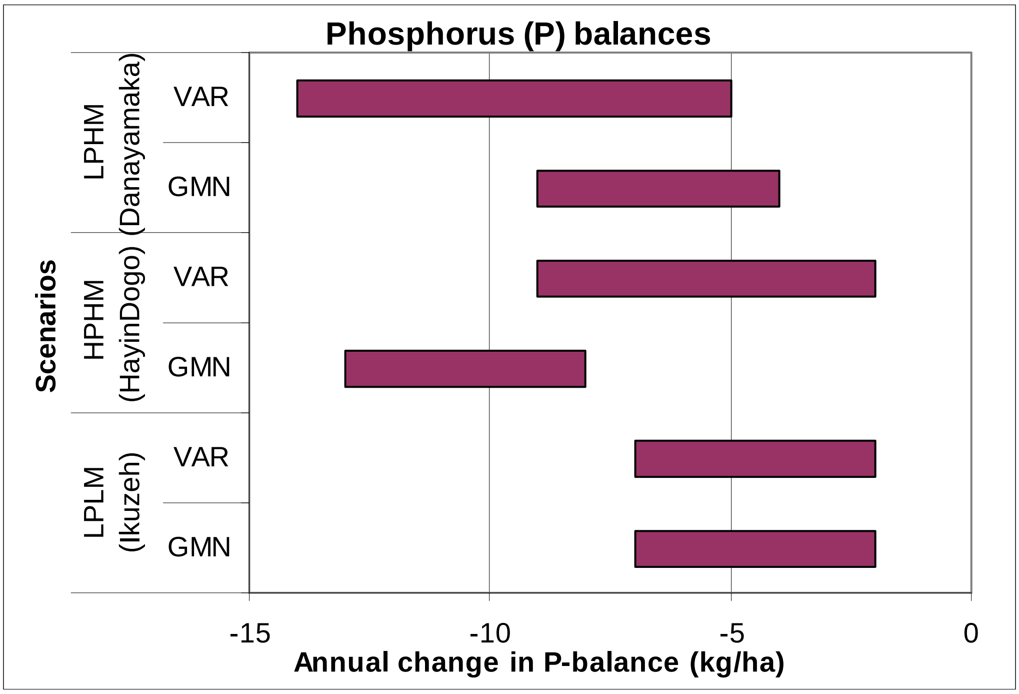

Figure 3.2: the range of the phosphorus (P) balances for maximization of gross margins and minimization of variance of the production plan. The lower bound represents the case in which all crop residues are removed from the field; the upper bound the case in which all crop residues are left in the field.

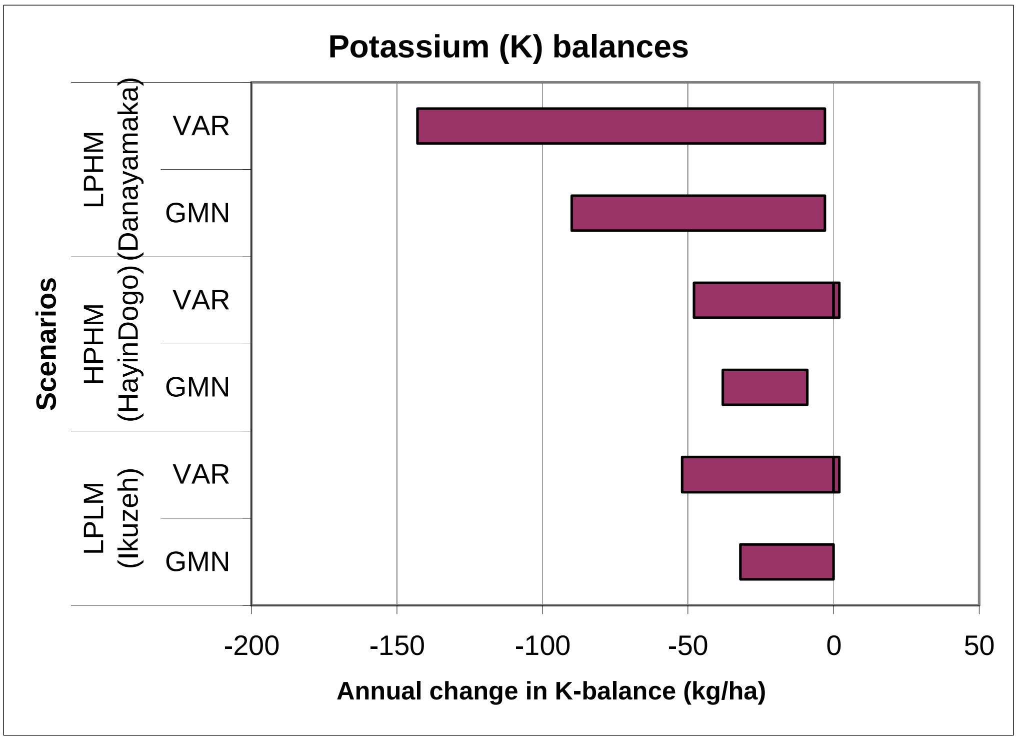

Figure 3.3: the range of the potassium (K) balances for maximization of gross margins and minimization of variance of the production plan. The lower bound represents the case in which all crop residues are removed from the field; the upper bound the case in which all crop residues are left in the field.

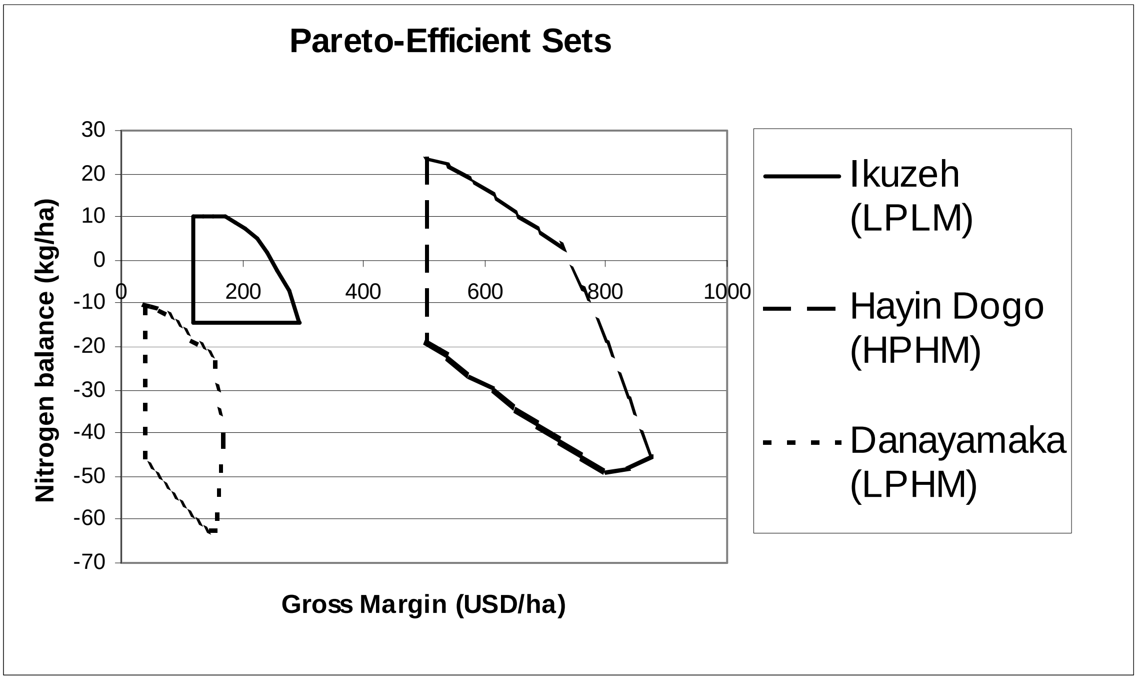

Figure 3.4: the Pareto-efficient production set for an average farmer in each location of study. The Pareto-efficient set is composed of all feasible production plans, valued in terms of gross margins and the resulting nitrogen balance.

Moreover, the right-hand side boundaries of the Pareto-efficient sets are steep, indicating relatively small initial trade-offs, when moving away from the ideal value for Gross Margin. In other words, if small reductions in Gross Margin are acceptable to farmers, N-sustainable production farm plans are feasible.

The trade-off between Variance and Sustainability (Figure 3.5) again shows that the Pareto efficient set in the LPHM-domain only contains negative nitrogen balances. For the other domains, the optima for Sustainability have high variances. The trade-off between Sustainability and Variance, as given by the boundary of the sets on the left-hand side, is steep as well, indicating that if small increases in Variance are acceptable, N-Sustainability is feasible.

As mentioned, Figures 3.4 and 3.5 are relevant for situations in which only two attributes are relevant to a farm household. It might well be that the farm household considers more than two attributes, and any point within the sets shown (though on the edge of the Pareto-efficient object in hyper space) can be Pareto-efficient. Hence, the next section looks in more detail into the differences in priorities set by individual farm households.

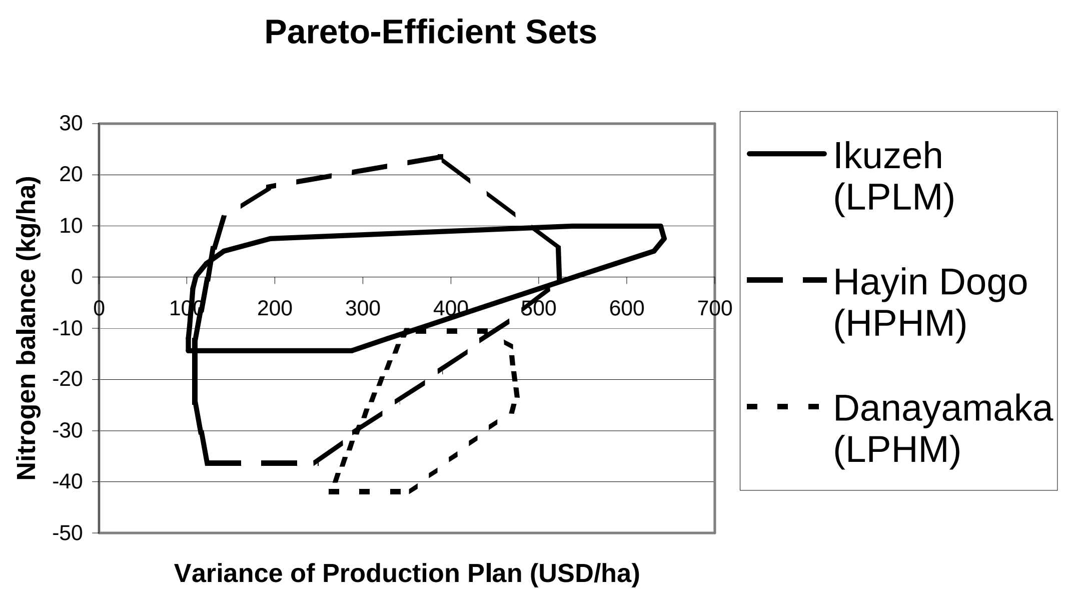

Figure 3.5: the Pareto-efficient production set for an average farmer in each location of study. The Pareto-efficient set is composed of all feasible production plans, valued in terms of variance of the production plan and the resulting nitrogen balance.

3.5.2 Determining weights of a MAUF.

We apply the MAUT-methodology (Section 3.3.3) to 105 households out of the 120 households in the dataset. We disregard 15 households from the analysis due to incomplete input-output data. Out of these 105 farmers, the model is initially infeasible for 21 farmers. This group is further analysed in two ways. First, the level of nutrient requirements is reduced to 70% of the FAO (2004a) standards, since the data collected on off-farm income could be an underestimate for some farmers. Secondly, we have reduced the farm size, a binding constraint in the simulations for some farmers. After simulation we scale the simulation results proportionally to equal actual use of farmland, as stated in the surveys. This allows us to use data for an additional 8 farmers, while data of 13 farmers cannot be used further. Unfortunately, the methodology used cannot be modified to estimate the attribute-weights for this group without making highly arbitrary model changes, such as further reducing subsistence levels or assuming higher levels of off-farm income.

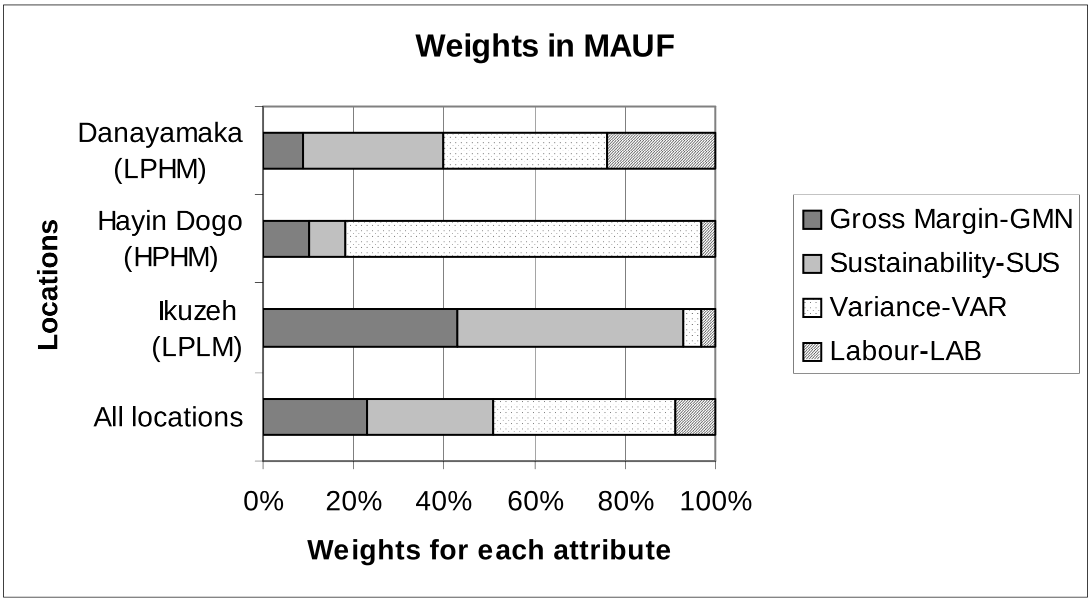

Figure 3.6: Average of calculated weights for four production attributes included in the multi-attribute utility function in each location of study.

Figure 3.6 presents the weights of the various attributes in the MAUF, calculated for each farm household and shown as averages per village, as well as the total average. In both villages with high market access, Variance is the most important, while Labour plays a larger role in the low population density domain, where average farm sizes are larger and labour shortages could arise. The average weight for Variance is low in the LPLM-domain, where Gross Margin and Sustainability seem to be the most important attributes for farm households. A likely explanation is that in this domain few high-value crops, with higher variances, were included in the model, since these were not observed in reality. Hence, by excluding these options from the analysis, all farm households appear to be less risk-averse than in the other domains. More general, if different production matrices are included in the models, based on different production methods across locations, it is not possible to compare the results between the different locations. This is a drawback of the method, since the omission of certain cropping options can influence the results.

3.5.3 Statistical analysis

In order to increase understanding of possible factors underlying heterogeneity in farm household production plans, we analyse the weights as follows. First, we determine pair-wise correlations between the weights obtained and various socio-economic variables, as well as between socio-economic variables, per village and at aggregate level (Table 3.5). Secondly, we use clustering methods to determine groups with homogeneous production attributes.

The aggregate correlations in Table 3.5 show that a less risk-aversive attitude is associated with a high focus on Gross margins and/or Sustainability, given the negative correlations. Furthermore farm size correlates negatively with Variance minimization, indicating that farm households with smaller land holdings cannot afford strong variations in production, as that would threaten food security.

Farm size and completion of primary education correlate positively with a stronger focus on Gross Margin, since larger farms allow farm households to produce for the market in addition to subsistence production. Furthermore, weights for Gross Margin correlate negatively with herd size and positively with other income sources. These results seem conflicting. A larger herd could generate the necessary cash resources, while cropping serves food subsistence and animal fodder requirements, hence a lower weight for Gross Margin. The same argument could hold for other sources of income. On the other hand, both larger herd size and off-farm income improve the financial status of the household, thereby allowing higher farm investments and a stronger focus on Gross Margin generation on the farm.

A stronger focus on Sustainability tends to be associated with older and better-educated farmers. On the other hand, other income sources and the weights for Variance and Labour use minimization correlate negatively. This suggests that farmers with a stronger off-farm focus tend to be less concerned with Sustainability, possibly since farming is not their only or primary source of income.

Moreover, high emphasis on Sustainability goes along with increased fadama ownership, allowing the cultivation of high-value crops associated with higher input use with positive effects on soil nutrient balances. Finally, a stronger focus on Labour minimization is positively correlated with livestock ownership. This suggests that some farmers choose farm plans which are low in required labour, in order to invest in, or because they have labour fixed to livestock activities.

The correlations at village-level largely tell the same story. In the LPLM-domain however, Labour use minimization correlates negatively with herd size, assets and household size. Probably the desire to increase available leisure time plays a role in these relatively rich households that are likely to have less problems in meeting subsistence demands.

Table 3.5: Selected pairwise correlations for each domain

Attribute	*Domain*	*Weight GMN*	*Weight SUS*	*Weight VAR*	*Weight LAB*	*Herd Size*	*Assets*	*Spent on hired labour*	*Total NPK application*	*Total urea application*	*Size of total farm*	*Size of fadama farm (riverbed fields)*	*Total people in household*	*Household members with other income sources*	*Age*	*Primary Education accomplished*
Weight GMN	HPHM	1.00	-0.01	-0.77**	-0.09	-0.06	-0.20	-0.16	-0.21	-0.16	0.09	0.05	-0.05	0.13	0.24	-0.31*
	LPHM	1.00	-0.31*	-0.19	-0.05	-0.10	-0.08	-0.07	-0.14	0.15	0.17	-0.20	0.12	0.16	-0.12	0.34*
	LPLM	1.00	-0.97**	-0.15	-0.19	-0.33*	0.06	-0.06	-0.17	0.02	0.21	-0.13	-0.21	0.34*	-0.34*	0.03
	All	1.00	-0.33**	-0.44**	-0.14	-0.17*	-0.07	-0.13	-0.19*	-0.10	0.29**	-0.05	-0.01	0.21**	-0.02	0.24**
Weight SUS	HPHM		1.00	-0.51**	-0.09	0.07	0.28	0.15	0.07	-0.01	0.10	-0.01	0.02	-0.08	0.09	0.15
	LPHM		1.00	-0.47**	-0.30*	-0.12	0.10	-0.06	0.15	-0.05	0.00	0.10	-0.20	-0.13	0.29*	0.32*
	LPLM		1.00	-0.02	0.06	0.34*	-0.10	0.01	0.18	-0.04	-0.24	0.08	0.19	-0.30*	0.29*	-0.03
	All		1.00	-0.53**	-0.16*	0.01	0.02	-0.08	0.07	-0.09	0.09	0.17*	0.08	-0.15*	0.29**	0.25**
Weight VAR	HPHM			1.00	-0.25	0.04	0.05	0.00	0.05	0.12	-0.09	-0.02	0.05	-0.11	-0.20	0.12
	LPHM			1.00	-0.57**	-0.06	0.09	0.11	0.10	0.13	0.02	0.11	0.18	-0.04	-0.07	-0.21
	LPLM			1.00	-0.18	-0.22	-0.17	0.13	-0.21	-0.16	0.07	0.21	-0.15	-0.26	0.09	0.02
	All			1.00	-0.32**	-0.05	0.04	0.15	0.06	0.15	-0.28**	-0.12	-0.08	-0.15	-0.16*	-0.23**
Weight LAB	HPHM				1.00	-0.17	-0.12	0.10	0.16	0.01	-0.18	-0.10	-0.10	0.11	-0.09	0.15
	LPHM				1.00	0.25*	-0.15	-0.02	-0.18	-0.19	-0.12	-0.10	-0.06	0.07	-0.14	-0.29*
	LPLM				1.00	0.27*	0.45**	0.18	0.20	0.29*	0.09	0.05	0.35*	0.00	0.24	0.02
	All				1.00	0.31**	-0.01	0.06	0.05	0.03	-0.05	0.03	0.02	0.03	-0.14	-0.31**

The table shows correlations between the weights obtained from the multi-attribute utility function and several household characteristics

*** significant at 5%, * significant at 15%.*

The results of the cluster analysis (Table 3.6) show that some of the clusters (i.e., clusters 1 and 5) seem to be specific to one location, although village membership was not a cluster variable. All farm households (but one) in the LPLM-domain are members of either cluster 1, 2 or 3, with high attribute weights for Gross Margin (cluster 1) and moderately to high weights for Sustainability (clusters 2 and 3). In clusters 1 and 2 farm sizes are relatively large, allowing farmers with less concern for subsistence production to aim for higher Gross Margins and/or Sustainability. Average labour supply to agriculture is highest amongst farm households in clusters 2 and 3, while off-farm income is slightly lower than in the other clusters. Hence, these farmers depend more on agriculture and invest more in sustainable soil use.

The majority of the farmers from the other two domains are grouped in clusters 4 and 5, whereby cluster 4 contains a large group of strongly risk-averse farm households. Farm households in cluster 5 have a strong preference towards minimization of labour use in crop production. In the latter cluster, herd sizes are relatively large, household labour supply is low and off-farm income sources are relatively high. The stated value of assets and completion of primary education of this cluster are among the lowest, hence it appears that diversification into livestock and off-farm income, and the resulting need to minimize labour use in crop production, is a coping strategy for this group.

In the final step we construct an ‘average’ farm household for each cluster, with a Multi-Attribute Utility Function and calculate the utility-efficient farm plans, as shown in the lower part of Table 3.6. Clusters 2 and 4 are calculated for the two locations in which members were identified. The results show that soil nutrient mining is utility-efficient for all clusters, except for some farmers in cluster 2 and all farmers in cluster 3. In all other clusters at least one of the nutrient balances is negative. All nutrient balances are negative for Gross Margin-optimising farmers in cluster 1 and Labour-minimizing farmers in cluster 5. Potassium and phosphorus balances are strongly negative for the risk-averse farm households in cluster 4. This is related to the high share of cereals in the farm plan, of which the straw that is exported from the field is rich in potassium.

Table 3.6: Results of clustering farmers according to production weights chosen.

Cluster	*1*	*2*		*3*	*4*		*5*
Size	15	22		7	32		8
Members of cluster per village							
LPLM (Ikuzeh)	12	12		6	0		0
LPHM (Danayamaka)	2	7		1	15		10
HPHM (Hayin Dogo	1	0		3	23		0
Weights in MAUF							
Weight GMN (Gross Margin)	0.91	0.03		0.23	0.05		0.16
Weight SUS (Sustainability)	0.03	0.91		0.53	0.07		0.12
Weight VAR (Variance of Production)	0.05	0.01		0.23	0.84		0.02
Weight LAB (Labour Use)	0.01	0.05		0.01	0.04		0.70
Livelihood Assets[1]							
Livestock Ownership (TLU)	0.80	1.76		1.31	2.01		3.75
Household Members working on Farm (#)	3.40	4.26		4.00	2.58		1.80
Household Members not working (#)	3.67	3.47		2.90	4.32		4.20
Value of assets (Naira)	7423	8276		8645	9854		5623
Completion primary school (%)	80	74		80	34		0
Off-farm employment/jobs (%)	93	68		50	68		70
Farm Size (ha)	8.78	6.55		4.83	4.35		4.39
Fadama area (ha)	0.73	1.10		0.56	0.74		0.70
Average use of inputs[1]							
Expenditures on hired labour (Naira)	1577	1816		4360	9121		3170
Use of NPK (kg)	142	319		168	336		248
Use of Urea (kg)	170	182		135	413		220
Utility-efficient soil nutrient balances[2]:							
Domain:	LPLM	LPLM	LPHM	HPHM	LPHM	HPHM	LPHM
Nitrogen (N) (kg/ha)	-8	29	16	13	13	20	-4
Phosphorus (P) (kg/ha)	-4	3	1	2	-7	-7	0
Potassium (K) (kg/ha)	-13	11	-8	3	-51	-81	-1

The table shows the characteristics of the groups obtained after clustering farmers with similar weights in the multi-attribute utility function.

[1] *As obtained from the baseline survey*

[2] *Lower bounds whereby crop residues are removed from the field*

3.6 Discussion and conclusions

We show that emphasis on different production attributes yields different farm plans, with the associated differences in soil nutrient balances. Although many studies relate farm plans to soil nutrient balances, this is the first time that observed differences in production plans, production preferences and soil nutrient balances have been related to each other for farm households in SSA.

The results of this application of MAUT in SSA yield interesting insights; however three points deserve additional methodological research. Firstly, the weights derived from applying the MAUT-methodology are conditional on actual production possibilities, market imperfections and differences in subsistence requirements between households. Hence the weights between farmers in different locations cannot be interpreted and compared directly as differences in farmer preferences, such as those one would derive from an experimental approach (e.g., Binswanger, 1980). Instead the weights reflect conditional or constrained preferences. Even though the estimated weights likely correlate with actual preferences, additional research is required to determine the exact relationship, as well as determine their sensitivity to changes in the model assumptions.

Secondly, the weights are sensitive to the activities and technologies incorporated in the household model, as revealed by the low levels of risk aversion identified for the isolated and poorest location. Little is yet known about the variance and potential bias of the obtained estimates in this method. Hence, a two-stage approach in order to determine causal relationships, whereby the weight(s) obtained are regressed on a set of environmental variables, would likely result in biased estimates, similarly to the concerns of biased parameter estimates in two-stage DEA-approaches (Simar and Wilson, 2007). Consistent econometric estimation of factors affecting heterogeneity is likely to be plagued further by issues of endogeneity. This needs to be addressed in additional methodological research.

Thirdly, in the modelling approach followed we did not address spatial and temporal differences in soil fertility resources. Both heterogeneity at plot scale (e.g., Titonell *et al.*, 2007) and changes in nutrient balances over time will affect nutrient uptake and crop yield. However, the primary aim of this research is to introduce a method to account for behavioural heterogeneity in a bio-economic model in SSA, while the method itself can easily be extended and refined to account for such spatial and temporal differences. Availability of multi-period production data can thereby as well be used to determine stability and/or changes of the estimated weights across time.

Simulated optimal production plans for average resource-poor farm households in different locations, varying in agro-ecological conditions and market access, show that soil nutrient balances achieved in production plans aiming at maximizing gross margins and, evidently, maximizing sustainability, are more favourable than in those aiming at minimizing variance in production.

We find strongly negative lower bounds on the soil nutrient balances, especially for potassium, even for some Gross Margin-oriented farm households, when it is assumed that all crop residues are exported from the fields as forage. Upper bounds on soil nutrient balances are positive in some situations. However, more research is needed to examine the efficiency of technologies in which cereal residues and legumes are recycled through livestock and manure production under different production attributes. These could possibly play an important role in realizing positive nutrient balances, as well as in enriching soils with organic matter, a component we did not address in our analysis because of the modelling complexity.

Both higher Gross Margins and higher Sustainability can be attained through increased use of external inputs and a (partial) shift from cereals to high-value crops such as vegetables. However, the production variance in production plans with higher Sustainability and/or Gross Margin is high, which might be unacceptable for risk-averse small-scale subsistence farmers. Hence, a transition to more sustainable production technologies is more likely when the risk, associated with growing certain high-value crops is reduced, for example through the introduction of varieties that are less susceptible to drought, and the enhancement of economic incentives, such as well-developed input and output markets, for example for agrochemicals such as pesticides and inorganic fertilizers. Other policies aimed at improving access to commodity price information in rural areas, as well as credit facilities to enable cultivation of high-value crops by the least-endowed, most risk-averse households are likely to play a positive role as well.

Using MAUT, we identify broadly three groups of farmers differing in weights in their MAUF. Firstly, a group of well-endowed farmers with a stronger orientation on gross margins and sustainability is identified. An important finding is that the utility-efficient farm plans of such farmers are associated with positive or nearly positive soil nutrient balances. These farmers have higher levels of input use, different cropping patterns, and reduced or even reverted levels of soil mining. Further enhancement of market functioning and profitability of their farm production, given the importance gross margins play in their composite utility function, will most strongly benefit this group. This is in line with findings presented by Sissoko (1998) and Kruseman (2000), which show that (input and output) price incentives, as well as credit facilities, can reduce the intensity of soil mining, though these policies are most effective in well-endowed households.

Nevertheless, while some farmers are sustainable with regard to soil resources in our base scenario, a large number of farmers is not. Hence, secondly, many farm households with smaller land holdings are more vulnerable, as reflected in the attribute-weight for Variance minimization. These farm plans are associated with mostly negative nutrient balances. Negative soil nutrient balances are thus a combination of strong risk aversion of many farm households and low orientation towards market production. Hence, our findings suggest that those farmers are caught in a poverty trap with declining soil fertility status. For these groups of farmers the largest immediate gain in utility can be achieved by reducing levels of variation in crop production. Moreover, a reduction in yield variability in the crops found in sustainable cropping patterns leads to a win-win situation with improved sustainability and farmer utility.

Kruseman (2000) observed that the least-endowed, subsistence-oriented farmers do generally not benefit from policies aimed at improving the functioning of input and output markets. The importance of Variance minimization for the least-endowed farmers as observed in this study, suggest as well that such policies will not benefit this group, unless production risk is reduced greatly. This finding should further guide agricultural research in improving cropping systems and designing effective policies aimed at enhancing sustainable use of soil resources by the poorest farmers.

Finally, a group of less-endowed farmers diversifies in non-farm activities, leading to an increased focus on labour minimization in crop production, indicating competing claims on labour resources for farmers engaged in intensified livestock production. Such farmers, albeit a small percentage, will benefit most from the development of labour-saving technologies, such as more efficient weed control in high-value and labour-intensive crops, concurrently reducing labour use, increasing Gross Margins and benefiting Sustainability.

The positive soil balances in some of the baseline scenarios we find in this study, give a more optimistic view than other studies (e.g., Sissoko, 1998; Woelcke, 2006), but appear similar to those of La Rovere *et al.* (2008), who find a stabilization of nutrient balances of better-endowed farmers over time in Niger. In Mali, Sissoko (1998), Struif Bontkes (1999) and Kruseman (2000) all find negative balances in simulated base scenarios, while Woelcke (2006) argues that positive nutrient balances are feasible after certain policy interventions in Uganda, but at greatly reduced profits. The main difference with our results is that positive balances are found in the baseline scenario, hence without further simulated policy interventions, such as improved credit facilities or lowered transaction costs. While location-specific characteristics could play a role, a possible other explanation is that this difference occurs due to the modelling approach we followed, accounting for behavioural differences. Ruben *et al.* (2001) note as well that bio-economic model outcomes are highly sensitive to assumptions on farmers' behaviour. Clearly, the inclusion of identified heterogeneity in farmer behaviour in the objective function is critical for obtaining representative model results and for deriving effective policy recommendations.

The outcome of this case study confirm results from other bio-economic modelling approaches, that soil fertility decline cannot be reversed solely by technological innovation or appropriate policies, but that a package of site-specific innovations is required. Further research on the most effective policies to reverse soil fertility decline amongst the least endowed households is therefore still required, thereby explicitly accounting for behavioural heterogeneity, in order to achieve sustainable use of soil resources in the savannas of SSA.

Chapter 4

Assessing the effects of heterogeneity in soil fertility on cereal productivity and efficiency in northern Nigeria[*].

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[*] This chapter is under review as:
Berkhout, E.D., Coulibaly, O, Schipper, R.A., Kuyvenhoven, A. Assessing the effects of heterogeneity in soil fertility on cereal productivity and efficiency in Northern Nigeria. Submitted.

Abstract

The inefficiency in agricultural production systems in Sub Saharan Africa (SSA) is well documented. However production is dependent on natural soil fertility levels, while this is not always taken into consideration in production function estimations. This could lead to incorrect estimations of production efficiencies. We therefore examine the potential of two variables to proxy heterogeneity in soil fertility, while evaluating efficiency in sorghum and maize production in Northern Nigeria. Furthermore, we test and correct for endogeneity of the input variables included. Results show that the used soil fertility variables have significant effects on production, although not always of the expected sign. Secondly, the inclusion of such variables plays a critical role in the identification of inefficiency, as omitting such variables leads to a false conclusion in the case of maize. Finally, variation in labour availability is an important determinant of the inefficiency found in sorghum production. This finding re-iterates the critical task for agricultural researchers to develop efficient labour-saving techniques for smallholder farmers in Sub-Saharan Africa.

4.1 Introduction

A number of studies have estimated inefficiency in smallholder agriculture in Sub-Saharan Africa (SSA) (e.g., Weir, 1999; Okike *et al.*, 2001; Alene and Manyong, 2006), by using a Stochastic Production Frontier (SPF) and Cobb-Douglas and/or Translog functional forms. While these specifications of production functions are very popular with agricultural economists, they do not incorporate insights in plant growth from agronomy and related sciences, to account for differences in soil fertility. Ruben *et al.* (2006) note this problem as part of a critical difference in approaches between disciplines, where economic studies primarily aim at defining marginal returns on factor use, and biophysical sciences focus on determining yield response functions in heterogeneous production environments.

Indeed, low production levels on smallholder farms in SSA are perceived as the result of a combination of both agronomic and economic factors (e.g., Lee *et al.*, 2006), while spatial diversity in soils at farm or plot level is common (e.g., Vanlauwe *et al.*, 2002; Tittonell *et al.*, 2007). Hence heterogeneity in soil fertility and economics of factors should both be accounted for in production function estimations.

Bioeconomic production functions in agriculture have been proposed and developed. Many studies start from the Von Liebig type of production function, incorporating Von Liebig's principle of the limiting soil nutrient, which is relatively in shortest supply (e.g., Ackello-Ogutu *et al.*, 1985; Paris, 1992). Other approaches distinguish between growth-related inputs, such as land and fertilizer, and growth facilitating inputs, such as labour and capital (Zhengfei *et al.*, 2006). However, few of these applications focus on agriculture in SSA. An exception is the study of Ruben *et al.* (2006), who use a stepwise procedure in estimating a production function in Ethiopia. They explicitly account for the relationship between input use, input uptake and yields as disentangled by De Wit (1992), in order to determine options for improving input efficiency. A major drawback of this approach is the extensive data demand generated by a number of simulation modules.

While these interdisciplinary approaches address the need to further integrate biophysical and economic sciences to generate a better understanding of farm and plot level decisions and production, a drawback for empirical research is that properties for estimating technical efficiency have not (yet) always been established. An exception is the Von Liebig model (Holloway and Paris, 2002), but that has rarely been applied.

Indeed, not accounting for soil fertility differences in the estimation of production frontiers is acknowledged as a major concern (e.g., Sherlund *et al.*, 2002) and can lead to biased estimations of elasticity of inputs and efficiency levels. Some authors have therefore argued that production efficiency estimates are ideally restricted to small homogeneous production areas (e.g., Weir, 1999). However, only considering a small area of study limits the prospects of identifying determinants of (in)efficiency in a wider geographical context, such as access to markets or credit. While some of these problems are overcome by recently proposed meta-frontiers (e.g., Battese and Rao, 2002), establishing homogenous areas in practice is difficult, as heterogeneity starts at the plot scale (Vanlauwe *et al.*, 2006).

Hence a number of modified approaches have been proposed to account for heterogeneity in the production environment. Fuwa *et al.* (2007) estimate production frontiers for rice farmers in India, both at farm and plot level. They show considerable variation in technical efficiency estimates, with farm households appearing inefficient at aggregate farm level, while they produce nearly efficient on some plots. Sherlund *et al.* (2002) demonstrate that omission of environmental variables in a stochastic production frontier results in biased parameter estimates and overestimates inefficiency levels for rice-producing farm households in Cote d’Ivoire.

A second major concern in estimating production functions and technical efficiency is endogeneity. This problem arises, as farmers are likely to adjust variable input use, depending on observed weather conditions. E.g., if rainfall is lower than expected, farmers may decide to use lower levels of fertilizer as well. Furthermore, if input use is endogenous, then (changes in) soil fertility indicators, which directly depend upon e.g., fertilizer use and cropping intensity, are endogenous too. Both, omitting soil fertility characteristics and not addressing endogeneity leads to inconsistent estimation of the parameters in the production function. Although both issues are widely recognized, very few researchers actually test or correct for both of them, Bagamba (2007) and Barrett *et al.* (2008) being recent exceptions.

In this study, we assess the effects of soil fertility differences on the productivity and efficiency levels of both maize and sorghum, the two most important crops in the savannah regions of Northern Nigeria, and estimate efficiency in production systems of both crops. However, production functions can generally not be estimated in a primal form in the case of multiple outputs. As a result, possibilities for estimation of technical multiple output efficiency using econometric techniques are limited. Just *et al.* (1983) and later Kumbhakar (1996) show how the dual representation of a production function, under cost minimization or profit maximization, can be used to estimate a multiple output function as well as efficiency levels. It is, however, unrealistic to assume smallholder farmers in SSA to maximize profit or minimize costs, as such an assumption ignores important production attributes such as a stable food supply and risk aversion. As a result, policy advice derived from a cost or profit optimisation framework is not likely to be the most effective. We therefore do not make any behavioural assumption, apart from the trivial one that more is always better. While this does not allow us to estimate a joint production function in the fashion of Just *et al.* (1983), efficiency levels and/or distance functions can still be estimated for crops separately.

A major constraint to accurately include heterogeneity in interdisciplinary production functions, or to estimate production functions including environmental variables, is the lack of reliable data. In SSA, detailed data on soil fertility and input use at plot or farm level, combined with socio-economic characteristics are rare, for various reasons such as little interdisciplinary research. Thus, there is a need to develop alternatives (proxies) in the absence of better data. We therefore account for heterogeneity in soil fertility levels by incorporating two proxies, easily derived from farm production surveys. These variables are constructed to account for farm-level deviations from average village soil fertility levels. The first variable is the share of cereals in total cultivated area as used by Zhengfei *et al.* (2006) for potato growers in The Netherlands. Since no fallowing is observed in the region of study, these cultivated areas equal total farm size. The second variable expresses the share of backyard fields, or frequently referred to as inward fields, in the total allocation of fields to the crop under consideration. In addition, we test whether these ratios need to be treated as endogenous.

The second major concern of potential endogeneity is further addressed by using instruments. We estimate the resulting specification by using Seemingly Unrelated Regression (SUR) and Three Stage Least Squares (3SLS), thereby effectively exploiting correlations between the error terms of both production specifications. Moreover, the instrumentation of endogenous variables allows us to gain insight in exogenous determinants of crop choice and input use.

We find that some of the parameter estimates of the ratios are indeed significant and can quantify their effect on crop production. More importantly, we find that including soil fertility-related variables has important consequences for tests on the presence of inefficiency, while determinants of technical efficiency before and after correcting for endogeneity differ. This should serve as a warning to researchers on interpreting stochastic frontier estimation results directly.

To our knowledge, this is the first time efficiency levels in sorghum and maize production are assessed jointly in Northern Nigeria. Earlier, Alene and Manyong (2006) investigated efficiency in cowpea production and Okike *et al.* (2001) efficiency in total farm output in the region. Although this study does not yet fully capture recently proposed interdisciplinary production functions (e.g., Zhengfei *et al.*, 2006), our approach is an improvement for analyzing production processes at smallholder farms in SSA. In Sections 4.2 and 4.3 of this study we describe the methodology and data used respectively. Section 4.4 presents the main results, which are discussed in Section 4.5.

4.2 Empirical Model

In the remainder of this chapter we assume that the yield of a typical cereal crop in the target area can be modelled as:

$$y = G(x) \cdot F(z) \qquad (4.1)$$

Where y is a yield level of the cereal crop; $G(x)$ is a common crop production function with a Cobb-Douglas or Translog functional form, based on five inputs: land, labour, inorganic fertilizer, capital (the measured value of farm tools) and livestock ownership (as a proxy for the use of organic fertilizer). We include heterogeneity in soil fertility through a scaling function $F(z)$. Unlike Zhengfei *et al.* (2006), the model does not distinguish between inputs directly affecting growth, such as fertilizer, and variables which facilitate growth, such as labour, capital and pesticides, since capital and labour data are not available at crop level.

4.2.1 Accounting for soil fertility

The growth facilitating function *F(z)* takes a value between 0 and 1, and is defined as a function of two proxies z_1 and z_2, hence $F(z) = F(z_1, z_2)$, in which z_1 is the share of cereal crops in total farm size (*Cereal ratio*) and z_2 is 1 minus the proportion of the crops grown in backyard fields (*Backyard ratio*) (i.e., the proportion of crops not grown in backyard fields). It is expected that a narrower rotation, i.e., a higher cereal ratio, depletes soil fertility and builds up disease pressure over time. Consequently, farmers with narrower rotations operate under less favourable growing conditions, so that yields are below their potential. Moreover, backyard fields, or in general fields closer to the homestead are characterized by higher soil fertility due to application of domestic waste, manure of free-roaming animals and excreta of humans. Hence, cultivation of a larger proportion of the crop on these richer soils leads to higher yields, closer to their potential.

Furthermore, we hypothesize that the effect of both ratios is not necessarily the same across the area of study. For example, the main difference between infields and outfields is likely to be a higher soil organic matter content in the former. Soil organic matter plays a crucial role in soil moisture retention (Bell and Van Keulen, 1995), and therefore, the effect of growing crops on backyard fields might be relatively stronger in drier areas. To account for such interactions, we include additional cross-terms between the ratios and village dummies. Hence *F(z)* takes the following form:

$$F(z) = \exp[\beta_{10} z_1 + \beta_{20} z_2 + (\sum_{k=1}^{M} \beta_{1k} D_k z_1 + \beta_{2k} D_k z_2)] \qquad (4.2)$$

in which, D_k is a dummy variable, set to 1 when the household is located in village k and zero otherwise. If the parameter estimates β_{1k}, β_{2k} are jointly zero for $k \geq 1$, there are no village-specific effects. By including (4.2) in a Translog production function (4.1) and linearizing by taking logs, we obtain the following function for maize and sorghum, whereby x_i represent input variables such as labour and fertilizer use:

$$\ln y = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln(x_i) + \sum_{i,j=1}^{N} \alpha_{ij} \ln(x_i) \ln(x_j) + \beta_{10} z_1 + \beta_{20} z_2 + \sum_{k=1}^{M} \beta_{1k} D_k z_1 + \beta_{2k} D_k z \qquad (4.3)$$

If the parameter estimates α_{ij} associated with cross-products of inputs are zero, the above formulation reduces to a Cobb-Douglas function. If parameter estimate β_{1k} is significant and negative for $k \geq 0$, the yield decreases with a factor between $exp(\beta_{1k})$ and 1, since $z_1 \in [0,1]$. When z_1 is close to zero, meaning that the share of cereals in total farm output is small, crop yield is expected to be closer to its potential. The same holds for β_{2k}: when negative and significant, yield is reduced with a factor between $exp(\beta_{2i})$ and 1, since $z_2 \in [0,1]$. When z_2 is close to zero, meaning that all crops are grown on backyard fields, yield is expected to be closer to its potential. Finally, we include average soil fertility data at village levels.

In this way we assume that within-village soil fertility heterogeneity is adequately captured by both z_1 and z_2. We do not further differentiate between the components making up soil fertility and their respective effects. Instead z_1 and z_2 reflect aggregate soil fertility. While this is a simplification in terms of plant growth processes, the method might be still be fairly appropriate.

As the first step we estimate (4.3) by assuming a Translog specification for both crops by using iterated Seemingly Unrelated Regression (SUR). This estimation method is econometrically more efficient since it exploits likely correlation between the error terms in both production functions, because local climatic conditions are likely to affect both crops simultaneously.

4.2.2 Accounting for endogeneity

In the second step, the concerns of endogeneity are addressed, by applying the Durbin-Wu-Hausman test. The rationale behind this test is to investigate whether the loss in efficiency induced by correcting for endogeneity, i.e., by using 2SLS, is compensated by a significant gain in consistency (i.e., Verbeek, 2004). The test is carried out by estimating a reduced form equation of the potential endogenous regressor from all predetermined or exogenous variables in the model. E.g., if farm size devoted maize production, x_1, should be treated as endogenous, equation (4.4) is first estimated, with y_i being all exogenous variables (i.e., instruments) available. The residuals η_1, are subsequently included in the production function and tested if the associated parameter is significantly different from zero. If that is the case, OLS does not give consistent estimates.

$$x_1 = \sum_{i=1}^{N} \gamma y_i + \eta_1 \qquad (4.4)$$

After identifying the endogenous variables, the model is re-estimated using 2SLS for both crops separately. The Sargan's test is applied to test on instrument validity, and we apply the rule of thumb by Stock & Watson (2003) to avoid using weak instruments. In Section 4.4 we discuss the potentially endogenous variables included in the model. Finally, we estimate the model for both crops jointly using 3SLS, thereby accounting for the identified endogenous variables. Like SUR, this estimation method is more efficient than separate regressions, since it exploits likely correlation between the error terms in both production functions.

4.2.3 Stochastic Frontier Analysis

We assume that (4.2) possibly takes the shape of a stochastic production frontier (SPF), as proposed by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). We therefore separately test for the presence of output technical efficiency, defined by the under-achievement of the output potential given the input-mix used, by applying a Likelihood Ratio test. Hereby the inefficiency term is assumed to follow a half-normal distribution. If the null hypothesis of no inefficiency is rejected, the model is re-estimated as a stochastic frontier model. Since heteroskedasticity may exist in the distribution of the inefficiency component, a number of strictly exogenous household variables to explain this farmer-specific heterogeneity are included in the analysis.

4.3 Data and setting

Detailed data are collected in 2001, on crops grown, field size and production quantities in three locations, for 40 farmers in each location. The three locations surveyed, Ikuzeh, Hayin Dogo, and Danayamaka are villages in the Northern Guinea Savannah (NGS) in which IITA carries out participatory technology evaluation. The latter two villages have good access to markets, while the first is slightly more isolated.

Table 4.1: Mean soil properties in the three villages

Village		*Ikuzeh*	*Kaz. Magani (Ikuzeh)*	*Hayin Dogo*		*Danayamaka*			
Source		1	2	1	1	1	1	2	3
Sample depth		(0-15 cm)	-	(0-15 cm)	(15-30 cm)	(0-10 cm)	(10-30 cm)	-	-
pH (H_2O)		6.2	5.2	5.0	5.0	5.8	5.9	5.4	6.1
Org. C (g kg^{-1})		6.9	10.3	5.8	4.6	6.6	6.2	4.7	5.5
N (g kg^{-1})		0.39	0.78	0.47	0.40	0.43	0.43	0.37	0.46
P (mg kg^{-1})		2.9	-	9.3	3.8	11.9	2.2	-	5.1
Exch. cations	Ca	1.4	2.67	1.3	1.6	2.1	2.7	2.12	2.24
(cmol kg^{-1})	Mg	0.52	1.26	0.39	0.54	0.65	0.88	1.05	0.66
	K	0.20	0.09	0.17	0.16	0.30	0.24	0.26	0.32
	Na	0.48	0.33	0.17	0.11	0.55	0.49	0.32	-
Exch. Acidity		0.17	-	0.22	0.23	0.10	0.10	-	0.67

Sources: (1) Franke et al. (forthcoming), (2) Nwoke et al. (2004), (3) Vanlauwe et al. (2002)

Vanlauwe *et al.* (2002), Nwoke *et al.* (2004) and Franke *et al.* (forthcoming) describe soil characterization in this region. Table 4.1 shows the main characteristics observed in these studies. Vanlauwe *et al.* (2002) find largely similar soil characteristics in the study region, based on randomly selected plots in two villages, one of them being Danayamaka. Nwoke *et al.* (2004) find considerable differences between Kazuwa Magani, a site close to Ikuzeh, and Danayamaka, with organic carbon, nitrogen and phosphorus being higher in the former. Franke *et al.* (forthcoming) provide the most detailed soil characterization, based on 106 soil samples in the three villages analyzed in this study. We therefore further use that information in our analysis.

The number of soil variables is reduced by using principal component analysis. It shows that village average soil fertility data reduces to two factors (Table 4.2), whereby soil factor 1 primarily describes variation in exchangeable cations (e.g., Calcium, Magnesium, Potassium, Sodium and ‘acidity’) and Phosphorus, while soil factor 2 describes variation in Nitrogen, Soil Organic Matter, pH and also Phosphorus. As the soil factors are village averages, an alternative would be to use village dummies. However, we expect that the village-specific variation in production is better captured by the variation described by these two factors.

Table 4.2: Factor loadings from principal component analysis on soil fertility data

	Soil Factor 1	*Soil Factor 2*
Org. C	0.34	0.94
N	-0.09	-1.00
P	0.64	-0.77
pH	0.28	0.96
Exch. cations (Ca)	1.00	-0.01
Exch. cations (Mg)	0.92	0.40
Exch. cations (K)	1.00	0.10
Exch. cations (Na)	0.72	0.70
Exch. Acidity	-0.95	-0.31
Predicted factors:		
Ikuzeh	-0.55	1.22
Hayin Dogo	-0.85	-1.19
Danayamaka	1.42	-0.18

Factor loadings > 0.5 are underlined

In addition, data is available on household size, age, education level, non-farm income sources and livestock ownership. Out of the sample of 120 farmers surveyed, 105 farmers grow maize, while 103 grow sorghum; after removal of outliers, the size of the data sets (N_m and N_s) are 94 and 97, respectively, out of which 84 farmers cultivate both crops.

Yield data per crop is collected at farm scale, while fertilizer use data is collected at field scale. Total field size and input use per crop are estimated as follows. For each farm, all fields with sole cropped sorghum or maize or fields cropped in a traditional cereal-cowpea relay system are added, plus the share of intercropped fields where maize or sorghum are grown with other crops. The share is assumed to be proportional to the number of crops grown on such fields.

No detailed information on labour use is collected. An attempt to construct estimates of labour supply in each crop based on labour data collection in the same region, as well as household size and other crops cultivated, is abandoned, due to strong multi-collinearity between these estimates and farm size. We use household members involved in agriculture as total labour supply to both crops.

We include livestock ownership (measured in standard Tropical Livestock Units) as a productive input, since it is likely to be strongly correlated to actual use of manure and actual input quantities were not recorded in the survey. Finally, we include capital, measured as the total value of farm tools and assets, as an input variable.

The cereal ratio is computed as the proportion of total farm size cultivated with cereals (maize and sorghum). The backyard ratio is defined as the proportion of so-called backyard fields in the total farm. Backyard fields are defined as fields close to the homestead (within a three-minute walk). Descriptive statistics of the factors and the ratios used in the production function are presented in Table 4.3.

Table 4.3: Descriptive statistics of factor use in production functions

Variable:	*Unit:*	*Maize* *N_m= 94*		*Sorghum* *N_s = 97*	
		Mean	(Std. Dev)	Mean	(Std. Dev)
Yield	Kg	971	991	1067	1031
Field Size	Ha	1.16	0.89	1.93	1.66
Labour use	Hrs	554	374	549	365
Fertilizer Use	Kg	127	118	135	193
Livestock ownership	TLU	1.72	2.57	1.39	1.73
Capital	Naira	9022	15151	7398	12226
Cereal Ratio	%	0.57	0.20	0.58	0.18
Backyard Ratio	%	0.61	0.46	0.81	0.38

In addition, some exogenous variables may influence the distribution of technical efficiency levels, while they could equally serve as instruments (Table 4.4). The variables in Table 4.4 could serve either purpose, as they are assumed to be fully exogenous in this production model. The effect of the variable *Age* of the farmer may be ambiguous, older farmers could be either more efficient at farm work due to experience, or less efficient due to lower physical condition. Both, *TLU per hectare* and *Capital per hectare*, are expected to increase efficiency, through increased liquidity. Increases in *Household labour per hectare* is expected to improve quality of labour application. *Household Ratio* denotes the ratio of household members not actively participating in farm operations and household members who do participate. A high value of this ratio could lead to increased efficiency, due to greater pressure on the working members of the household, a lower ratio could also lead to increased efficiency, due to higher labour availability and better timing of farm operations.

Table 4.4: Exogenous household characteristics used in efficiency analysis as well as instruments

Variable:	*Unit*	*Mean*	*Std. Dev.*
Age (0=below 19, 1= between 19 and 50, 2 = above 50)		0.29	0.48
TLU per hectare	#	0.38	0.48
Capital per hectare	Naira	1910.66	2729.52
Household labour per hectare	#	147.43	137.48
Household Ratio	#	1.66	1.49
Distance to main road	Km	6.63	2.75
Gandu (0 = no, 1 = yes)		0.86	0.35
Other Income (0 = no, 1 = yes)		0.67	0.47

Farmers who have better access to input and output markets, expressed in a proxy (*Distance To Main Road*), are likely to be more efficient due to more timely application of inputs. Membership of the traditional Gandu-system (*Gandu*), associated with greater responsibilities of the household head, could lead to higher efficiency. Farmers that have off-farm income (*Other Income*) might be less efficient, since labour is allocated to these tasks, with possible negative effects on timeliness of farm operations. However, off-farm income might also lead to greater efficiency, since greater liquidity enables purchases of other inputs at the right moment (no data on other inputs was available).

Finally, additional information is derived from participatory field meetings in the same region in 2007, one being held in Ikuzeh, assuming that some of the general results from these interviews are indicative for the analysis in this research as well.

Farmers were, amongst others things, asked to list the main production constraints in a group setting. Farmers in Ikuzeh village listed labour supply as the main constraint, while high fertilizer prices and uncertain supply ranked second. In all other locations high fertilizer prices and uncertain supply ranked first, followed by labour issues in second or third place.

Based on the high importance of labour issues in all locations, farmers were asked to give a ranking of crops, to which they would preferentially supply labour in case of labour shortages. In these rankings maize is always considered more important than sorghum, as the risk of crop failure is higher in case of neglect. Issues of marketing did not play a role in this choice as both maize and sorghum are main staple crops and marketed regularly.

4.4 Results

We first estimate (4.1) for the case that *G(·)* takes a Cobb-Douglas or a Translog functional form using Ordinary Least Squares (OLS). We test for improvement in fit of using a Translog-specification instead of a Cobb-Douglas. The null hypothesis of no improved fit in Translog is rejected at 1% significance level for both crops, and throughout the remainder we maintain a Translog specification. The parameter estimates for coefficients of maize and sorghum are provided in Table 4.5.

We first estimate both equations separately, using OLS and retain the most parsimonious specification (Model 1). It shows that the cereal ratio does affect maize production, but not sorghum. The effect on maize production differs across locations and is strongest in Ikuzeh, while it is positive in Danayamaka. Furthermore, while the backyard ratio has a negative effect on sorghum production, the effect is positive for maize production in Hayin Dogo.

The Likelihood Ratio-tests on inefficiency do not reject the null hypothesis of no inefficiency in both crops, as shown in the first column of Table 4.6. The second column shows the result of this test when we remove all soil fertility-related variables from this specification, i.e., both ratios, their effects at village scale, as well as the two main soil factors, and introduce village dummies instead. For both crops the test statistic increases considerably, and the null hypothesis of no inefficiency is rejected at 5% and 6% for maize and sorghum, respectively.

Table 4.5: Parameter and elasticity estimates

Crop	*Maize*			*Sorghum*			
Model	OLS 1	SUR 2	3SLS 3	OLS 1	SUR 2	SFA 2a	3SLS 3
Adjusted-R²	0.72	0.80	0.77	0.75	0.81	n.a.	0.82
Corrected for endogeneity[1]	no	no	yes	no	no	no	no
Socio-economic variables[2]							
Farm size	0.60	0.42	0.97	0.48	0.40	0.74	0.41
Fertilizer use	0.41	0.31	0.29	0.35	0.27	0.24	0.28
Household labour availability	0.01	-0.07	-0.10	0.44	-0.02	-0.01	-0.02
Hired labour use		0.04	0.03			-0.01	-0.01
Capital availability		-0.60	-0.65	-0.04	-0.08	-0.04	-0.08
Livestock ownership	-0.03	-0.19	-0.24	0.04	0.14	0.23	0.14
Bulls		0.15					
Soil fertility variables[3]							
Soil factor 1		-0.34	-0.36	0.23	0.29	0.26	0.30
Soil factor 2	0.48	0.37					
Cereal ratio (Ikuzeh)	-2.24	-2.18	-1.62			-0.41	
Cereal ratio (Hayin Dogo)	-0.05	-0.70	-1.62			-0.41	
Cereal ratio (Danayamaka)	0.27	0.17	0.64			-0.41	
Backyard ratio (Ikuzeh)				-0.36			
Backyard ratio (Hayin Dogo)	0.55	0.48	0.53	-0.36	0.33		0.33
Backyard ratio (Danayamaka)				-0.36			
Variables affecting distribution inefficiency[4]							
Age group						1.07	
TLU/ hectare							
Capital / hectare							
Household labour / hectare						-0.01	
Household ratio							
Distance main road							
Gandu							
Other income							
Grows maize as well						-1.87	

[1] *Durbin-Wu-Hausman test suggests only one variable in the maize estimation needs to be treated as endogenous.*

[2] *Elasticities are calculated at sample means by using all parameter estimates significant at 10% significance level.*

[3] *Estimates are shown after accounting for village specific effects, thereby including variables significant at 10%.*

[4] *Variables shown are significant at 10%.*

In the second model both equations are estimated using SUR (Model 2). Table 4.5 shows that for both maize and sorghum the elasticities of inputs change considerably, especially with regard to household labour and capital availability. Furthermore, some of the signs associated with the ratios change, most notably the backyard ratio in sorghum production.

Table 4.6: Testing for inefficiency

Model number	*1*		*2*		*3*	
Estimation method	OLS		SUR		SUR (IV-estimates)	
	With soil fertility	Without soil fertility	With soil fertility	Without soil fertility	With soil fertility	Without soil fertility
Maize	0.00 (1.00)	2.92 (0.044)	0.00 (1.00)	1.87 (0.086)	0.00 (1.00)	3.89 (0.024)
Sorghum	0.73 (0.193)	2.61 (0.053)	5.94 (0.007)	7.00 (0.004)	6.78 (0.005)	6.41 (0.006)

Table 4.6 shows calculated values of the chi-squared statistic (p-value) of a Likelihood Ratio test on the presence of technical inefficiency assuming H_0: no inefficiency.

Based on the LR-tests on inefficiency, the null hypothesis of no inefficiency in maize is still not rejected, but is rejected in sorghum production at the 1% significance level. Thus, the estimation method, more efficient than OLS in econometric terms, now significantly identifies inefficiency, which had gone unnoticed previously. The sorghum specification is re-estimated as a stochastic frontier model with the variables in Table 4.4 included, to explain the distribution of the inefficiency component. The results are given in Table 4.5 (Model 2a). While the stochastic frontier estimations are largely similar to the SUR estimation (Model 2), the backyard ratio no longer enters the resulting equation significantly.

We next apply the Durbin-Wu-Hausman test to investigate whether endogeneity is a problem in the specification with regard to three variables. First, farm size devoted to crops can be considered as a function of the expected output, i.e., resulting from a certain farm plan envisioned. This could further be influenced by initial weather observations leading to an increase or decrease in certain crop areas. Second, if farm size of sorghum and maize is endogenous, then so is the cereal ratio. Finally, fertilizer input is potentially endogenous through similar reasoning. Two more variables are potentially endogenous, the backyard ratio and use of hired labour. However, as no suitable instruments are available for these variables, they are further treated as exogenous in the remainder of the chapter.

We examine endogeneity for each of these variables as well as all cross-products and squares in which they appear, using the potential instruments listed in Table 4.4. Table 4.7 shows the parameter estimates for the first stage regression of this cross-product. We find that the cross-product of fertilizer and farm size in the maize equation needs to be treated as endogenous. The Sargan test is not rejected at 5% and the reduced form estimate suggests the used instruments are not weak, as it passes the rule of thumb by Stock & Watson (2003). However as no alternative instruments are available we maintain this specification. It is somewhat puzzling that the cross-product needs to be instrumented for, while the level variables can be treated as exogenous. That said the test applied does not test on endogeneity itself, but rather identifies whether or not potential endogeneity affects the consistency of the estimation technique.

Table 4.7: Instrumented variable estimates maize equation

Dependent variable:	*Farm size* Fertilizer use*
F-value:	22.68
Total Farm	1.70 ***
TLU / hectare * Total Farm	-0.76 **

** significant at 10 %, ** significant at 5 %, *** significant at 1 %*

We re-estimate the system with 3SLS (Model 3). Note that endogeneity problems only affect maize production. The estimation of both sorghum and maize production in the same system therefore only serves to exploit correlation in the error terms between the two, not to account for an endogenous relationship. The parameter estimates in maize are largely similar, compared to the uncorrected models (Model 1 & 2), with minor changes in the elasticities. The LR-test still does not reject the null hypothesis of no inefficiency in maize (Table 4.6). Again, maize producers are found efficient, but only if accounted for heterogeneity in soil fertility.

4.5 Discussion and conclusion

The first major finding that emerges from our results is the significance of soil fertility indicators in production, although not always with the expected sign. The cereal ratio shows a significant effect in all three estimated models in maize production, albeit with different magnitudes and signs across the villages. It does not have a significant effect however, in sorghum production. The effect in maize production is strongly negative in Ikuzeh, less strong, but still negative in Hayin Dogo, while it appears positive in Danayamaka. A possible explanation for these differences could be the different P-levels (phosphorus) in the top soil, which are highest in Danayamaka and very low in Ikuzeh (Table 4.1). Possibly, the high P-levels in Danayamaka do not lead directly to the expected negative effect of the cereal ratio as a result of soil mining. Many authors indeed suggest that low P-availability is one of the main impediments towards increased cereal production in Northern Nigeria and other African Savannah regions (e.g., Nwoke *et al.*, 2002; Tabi *et al.*, 2008).

The backyard ratio has the expected negative effect in sorghum production in the initial OLS estimation, but is not significant in the subsequent models, except in the village of Hayin Dogo. We observe the same positive effect in maize production in Hayin Dogo. Apparently the backyard ratio does not affect production in the other villages likely because farmers in this location only grow maize on non-backyards fields, such as fadama fields, which are sufficiently fertile to sustain maize production. This reasoning suggests that the backyard ratio itself is endogenous, since a farmer decides on expected output levels, crop choice and crop allocation to fields jointly. However, as said before, no potential instruments are available to allow us to further analyze this point.

The average soil fertility variables, captured in the soil factors, play a significant role, but their effect is different in both crops. This is surprising since the expected response to changes in the main macronutrients should be largely similar for both (e.g., van Duivenbooden *et al.*, 1996). Hence other factors are likely to play a role. The effect of an increase in soil factor 1 is positive in sorghum production, but negative in maize production. This factor describes variation in exchangeable cations, including potassium and exchange acidity, whereby on average a high value of this factor represents low acidity and high exchangeable cations. A possible explanation for the positive effect in sorghum production could be that sorghum is more sensitive to acidity than maize (e.g., Akhter *et al.*, 2009).

Increases in soil factor 2, indicating lower nitrogen but higher organic matter levels, are associated with higher maize yields, but the parameter estimate is no longer significant at conventional levels in the 3SLS. Table 4.2 however shows that nitrogen and phosphorus load negatively on this factor, while OM loads positively. Hence the effect of increasing OM overwhelms the negative correlation of nitrogen content. This suggest that the level of organic matter content in soils plays a crucial role in maize cultivation, possibly due to higher levels of moisture retention, while it does not significantly affect sorghum production. However, the findings for both factors illustrate a drawback of reducing the soil variable data through factor analysis, since it is difficult to establish and interpret the individual effects of the soil fertility variables.

Furthermore, both ratios do appear to be effective proxies to account for heterogeneity in soil fertility, if financial or other constraints limit detailed data collection of soil characteristics. Both ratios are based on farm level surveys, and through this approach it is possible to jointly quantify inefficiencies in yield and account for differences in soil fertility. However the interpretation is not always straightforward because detailed on-farm soil data is not available. Nevertheless, the significant effects of both biophysical and socio-economic variables in this analysis demonstrate the need for further enhancing interdisciplinary research for the analysis of crop production. For example, the development of more robust fertility indicators, which can easily be derived from farm surveys, merits further joint research by economists and soil scientists. This in turn can be further used to recommend optimal input and soil fertility management strategies for sustainable agriculture in SSA.

The second main result is the inclusion of variables describing micro-topographical differences in soil fertility that are crucial in testing on the presence of inefficiency in a stochastic frontier framework. Not accounting for heterogeneity in soil fertility, both between farms and between locations in a stochastic frontier analysis, leads to considerably different results. As is shown in Table 4.7, all models of maize production, only including village dummies instead of soil fertility variables, would have led to the conclusion that maize producers are inefficient, while they are not when accounting for soil fertility heterogeneity. Although we do conclude in the final model that sorghum producers are inefficient, the LR-test statistics are consistently higher when omitting soil fertility data, leading us to reject the null hypothesis sooner. This is an important finding, given the surprisingly little number of stochastic frontier analyses that actually account for farm or plot level soil fertility differences. Our findings with regard to omitting soil fertility variables are in line with earlier findings of Sherlund *et al.* (2002) and Fuwa *et al.* (2007), who found considerable differences between models with and without soil fertility heterogeneity.

Finally, after correcting for endogeneity and heterogeneity in soil fertility, there is evidence of inefficiency in sorghum production, but not in maize. Due to inefficiency farmers in the target area produce on average 33% below their sorghum output potential (data not shown). An important finding relates to the exogenous variables explaining efficiency levels. Being a maize-grower, age and the labour-to-land ratio affect inefficiency levels.

Labour availability is widely known to influence crop decisions (e.g., Chianu *et al.*, 2007), but our results confirm that labour availability plays an important role as well in explaining efficiency levels. Larger families are more effective in covering the peak labour demands, e.g., during weeding and harvesting times. These results are not surprising given the importance labour constraints received in village participatory meetings. It further confirms that farmers, in case of labour shortages, devote available time to maize rather than sorghum, as observed by the full efficiency in the former production process. The results further suggest that the development of labour-saving techniques, such as small-scale mechanization harvesting techniques or labour saving weeding technologies, have a large potential for increasing productivity levels in sorghum, and potentially other crops, not included in this analysis, as well.

While increases in labour availability per hectare do reduce inefficiency levels, the elasticities present a somewhat different finding for both crops. An increase in total household labour availability gives a negative effect on cereal output. Similarly, increases in capital availability and livestock ownership negatively impact sorghum and maize production. It should be noted that these figures do not present actual allocations to crops, but are household totals. Hence these figures primarily suggest that an increase in these assets does not lead to further intensification of cereal production, but is likely to benefit other products or activities. This clearly suggests that farming techniques with higher returns to labour and capital are necessary in order to increase cereal production.

The importance of labour in agricultural production found in this study, does not correspond to other studies in the region. Okike *et al.* (2001) in the same region, as well as in other efficiency studies (e.g., Weir *et al.*, 1999), find large effects of age on efficiency levels, while Alene and Manyong (2006) find a large effect of the distance to markets (main roads). The former suggest that ageing of the household head negatively affects productivity levels, while the latter suggests that improvements in infrastructure aimed at reducing transaction costs and/or facilitating improved extension work, are likely to lead to productivity gains in sorghum production. Neither of these variables play a significant role in our results. While the age of a household head might have some effect on productivity, this effect is likely to become smaller in larger households.

We do not find any effects of distance to markets in our analysis, tough a word of caution is necessary here. Large village-specific effects are found in the soil fertility variables and these could be taking up part of distance-to-market effect, or be influenced by distance to markets themselves. Possibly large distances to input and output markets lead farmers to rely more heavily on disposable soil fertility stock, thereby leading to a inverse negative relationship between the two. Unfortunately, the limited scope of this study with three villages, as well as the limited detail in the distance to market variable, limit further analysis of this hypothesis.

In this chapter we re-emphasize the need to include both biophysical and socio-economic variables in the same framework of analysis. Although the approach does not yet fully capture all biophysical processes of crop production, it serves as an important step, while more refinements are still needed. These are urgently needed in order to derive unbiased efficiency and elasticity estimates, in order to recommend effective input and soil fertility management strategies for sustainable agriculture in SSA.

Chapter 5

Do non-tangible benefits of keeping livestock explain differences in crop-livestock integration? New insights from northern Nigeria[*].

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[*] This chapter is based on: Berkhout, E.D., Schipper, R.A., Van Keulen, H., Franke, A.C., Coulibaly, O. Do non-tangible benefits of keeping livestock explain differences in crop-livestock integration? New insights from Northern Nigeria. Paper under development.

Abstract

Crop-livestock integration (CLI) is widely advocated as a promising strategy to revert soil fertility decline at smallholder farms in the savannah regions in Africa. CLI is a multidimensional concept, comprising use of draught labour as well as manure use, while the level of crop-livestock integration differs considerable between farmers. No studies have yet analysed how non-tangible benefits of keeping livestock, such as insurance and financing, may explain observed differences in CLI. In this chapter we first show how efficient herd size increases for positive non-tangible benefits by using a farm household simulation model. Furthermore, the results from this model suggest that for increasing labour supply herd size decreases due to a shift into vegetable cultivation and consequent reduction in on-farm fodder supply. Secondly, we introduce a method to measure non-tangible benefits empirically by calculating the difference between simulated herd size at maintenance levels and actual herd size observations. A regression analysis shows that farm and household size as well as age, education level and soil quality affect explain differences in calculated non-tangible benefits. Finally, it is shown that herd size increases demand for fodder products, while there is additionally weak evidence that manure use increases cereal production, but does not benefit other crops. Additional research is needed to establish if the different components making up non-tangible benefits can be identified separately.

5.1 Introduction

Hunger and malnutrition among farm households in the dry and semi-arid areas of Sub-Saharan Africa (SSA) is often caused by an increasing population pressure, which leads to more intensive land use. Nevertheless, this increase in production is insufficient to adequately feed the growing population, while it also exhausts soil nutrients. Crop-livestock integration is often seen as a possibility to redress soil fertility decline and increase production. Using data from the savannah region in northern Nigeria, this chapter analyses forces driving crop-livestock integration (CLI).

Following the classical hypothesis of Boserup (1965), farmers intensify agricultural production when population pressure increases, due to a reduction in average farm size and an increase in food demand. An important step in the process of such intensification in the savannah region in West Africa is the emergence of crop-livestock integration, with the aim to improve the low indigenous level of soil fertility or to stop its further deterioration. CLI, also frequently referred to as mixed farming, represents a combination of techniques and practices, with the main focus on on-farm recycling of soil nutrients by feeding crop residues and other organic material to livestock and applying their manure to the land. Another important component of CLI is the use of draught power, supplied by bulls, thereby making it possible to expand the acreage cultivated and/or to increase the efficiency of labour.

While CLI is frequently being advocated as one of the most promising solutions to combat soil fertility decline and associated productivity losses in African agriculture (Sanginga *et al.*, 2003), the reasons as to where and when it occurs, and disappears again, are not well understood. The basic hypothesis formulated (McIntire *et al.*, 1992) describes how CLI at smallholder farms is a step on the ladder of intensification, thereby moving from an extensive and low-input arable farming system, to a slightly more intensive and integrated crop-livestock system, and finally to an intensive, specialized and market-oriented farming system. Nevertheless, while several studies acknowledge this hypothesis (e.g., Abdoulaye and Lowenberg-DeBoer, 2000; De Ridder *et al.*, 2004; Aune and Bationo, 2008), there are very few empirical studies which lay the hypothesis to test, thereby combining socio-economic and bio-physical factors to identify drivers of crop and livestock integration at farm level. Manyong *et al.* (2006) is a recent exception, paying specific attention to capturing the multi-dimensional facets of CLI, i.e., use of manure, use of draught power, and use of crop residues.

The aim of this chapter is to analyse two important aspects, not yet addressed in previous empirical studies on crop-livestock integration. First, an important motive to keep livestock to many smallholders relates to the non-tangible benefits of keeping livestock such as insurance or wealth storage in the absence of financial markets. The degree to which such benefits govern farmers' choice to integrate crops and livestock is unclear. Second, the differential effect of emerging cash crop opportunities to households is not well understood. More specifically, closeness to urban centres offers opportunities for intensified cash crop production, potentially lowering livestock densities for some farmers as a consequence of reduced feed supply from traditional fodder crops. This effect may differ among farmers in one location depending on differences in land and labour supply and access to markets. At the same time, however, non-tangible benefits of keeping livestock, such as wealth storage, are likely to be more important for some farmers in the presence of emerging cash crop opportunities.

In our analysis, detailed estimates of feasible herd size and their economic value are required. Therefore, in Section 5.3 we describe an effective methodology to calculate feasible herd size and liveweight gains, based on the relationship put forward by Ketelaars and Tolkamp (1992), and subsequently used in a number of other studies (e.g., Savadogo, 2000; Zemmelink *et al.*, 2003; La Rovere *et al*., 2005). Furthermore, in Section 5.3 we also briefly recapture the methodology to account for non-tangible benefits as introduced by Bosman *et al*. (1997) and further implemented by Moll (2005) and Moll *et al*. (2008).

In the first step of our analysis (Section 5.4), the estimates from Section 5.3 are incorporated in a farm household model to determine efficient farm plans for different types of farmers, in terms of both crop and livestock production. We thereby explore the relationship between non-tangible benefits and levels of crop-livestock integration –proxied through livestock density and manure supply– as well as how this relationship varies among different types of farmers.

Secondly, to complement these modelling results, we implement a statistical analysis in Section 5.5. While the importance of non-tangible benefits is frequently discussed, there have so far not been any studies that estimate such benefits empirically. Therefore, we introduce a novel method in this section to estimate non-tangible benefits of keeping livestock, and factors influencing variation in non-tangible benefits. Hereby, based on the livestock modelling procedure in Section 5.3, we first identify the largest herd size that can be kept at maintenance level in relation to actual fodder production. We subsequently identify factors leading farmers to deviate from these herd size. As well in this section, we identify determinants for increased use of manure in crop production to account for multiple factors that constitute CLI. In Section 5.6, the results are compared and discussed, particularly with regard to the opportunities for promoting livestock production for soil fertility management. We start with an overview of the main research on crop-livestock integration in Section 5.2.

5.2 Drivers of crop-livestock integration

The two main advantages of CLI relate to the possibility to improve the quality of soil resources by using produced manure as fertilizer. These advantages are (1) a rapid recovery of the nutrients harvested through plant uptake by manure production, and (2) the improvement of soil structure by increasing its organic matter content. However, these advantages can generally not be achieved simultaneously, since rapid recovery of nutrients also implies faster decomposition of organic matter. Nevertheless, CLI is often considered one of the most promising strategies to alleviate the adverse effects of soil fertility decline in SSA (e.g., Sanginga *et al.*, 2003). Notwithstanding the beneficial effects of CLI, simulation results have shown that external inorganic inputs remain necessary to maintain soil fertility levels, as there are inevitable soil nutrient losses in intensified closed systems (Van Keulen and Breman, 1990). Furthermore, the slow decomposition of organic matter, as well as its relatively low element concentrations require large quantities of organic inputs to satisfy crop demands (De Ridder and Van Keulen, 1990).

As argued by Manyong *et al*. (2006), CLI is a multi-dimensional concept that comprises various practices such as feeding of crop residues to animals, the use of manure in crop production, as well as the use of draught power. They suggest that CLI can be effectively captured by a single index using data reduction techniques. On the other hand, the authors observe that this index is positively correlated to livestock density, while exogenous variables do not affect the different components, making up

CLI, in a similar way. Hence, an increase in one of these components can not unequivocally be interpreted as an overall increase in CLI. Therefore, in this study, we do not attempt to capture CLI in a single indicator, but assume variation in CLI to be adequately captured in two variables: livestock density and manure use.

While explaining farmer decisions in integrating crops and livestock, several studies (e.g., De Ridder *et al*., 2004) identified differences in the level(s) of CLI. The main hypothesis put forward relates to differential access to markets (e.g., McIntire *et al*., 1992). Poor and/or isolated smallholders are excluded from capital and/or labour markets. Such farmers are likely to respond to the increasing demand for subsistence production resulting from an increase in population pressure, by increasing labour supply to subsistence crops. Slightly better endowed farmers can intensify by integrating crop and livestock production, whereby manure resulting from livestock production is used to compensate for the lack of access to markets for inorganic fertilizer. In the final step, the best-endowed farmers, who are well integrated into markets, can specialize in capital- and input-intensive cash crop or livestock production.

Abdoulaye and Lowenberg-DeBoer (2000) demonstrate in a modelling approach that farmers in Niger, who are well-integrated into capital markets, decrease use of organic fertilizer compared to less endowed farmers. However, farmers with good access to capital markets are usually well endowed, reflected in larger herd sizes to store wealth, which would suggest that manure supply actually increases. Hence, the result by Abdoulaye and Lowenberg-DeBoer (2000) is somewhat surprising, but a consequence of the fact that keeping livestock and manure production was not endogenously included in their model.

Marenya and Barrett (2007) similarly studied factors affecting adoption and dis-adoption of various integrated natural resource management techniques (INRM) in Western Kenya, including the use of manure, and also noted that livestock ownership increases the likelihood of applying manure. Moreover, they observed that combined use of organic and inorganic fertilizer increased over time, suggesting both inputs are complementary. An additional explanation might be that increased wealth, as stored in livestock, increases supply of manure, but also allows purchase of inorganic fertilizer. Nevertheless, Marenya and Barrett (2007) actually observe a decrease in per capita wealth over time. Additionally, they found that the type of crop grown on a field was an important determinant of whether INRM-techniques were applied, whereby

INRM-techniques mainly served to safeguard subsistence crop production, but not cash crop production.

In addition to the view that CLI results from increasing population pressure and differential access to markets, an alternative view explains the occurrence of CLI as an ideological process. In this view, governments and researchers promoted CLI driven by a romantic view of a self-sufficient peasantry. Hence, colonial administrators advocated CLI with a view of creating order in chaos (Sumberg, 1998; 2003). After colonial times, CLI persisted in filling an important role in development-oriented agricultural research, not primarily because it solves constraints at farm level, but since researchers were convinced of its benefits. This, in turn, has led to poor *ex ante* assessment of constraints at farm level. Moreover, it has given rise to a view of technology development as a “one-size-fits-all”.

Nevertheless, none of these studies on and explanations for crop-livestock integration explicitly account for the non-tangible benefits derived from keeping livestock. Bosman *et al*. (1997) and Moll (2005) have proposed a method to account for the various non-productive roles of livestock, such as wealth storage or insurance purposes. The rationale in those papers is to quantify such non-tangible benefits, based on (rough) estimates of, for example, insurance costs in nearby formal or informal insurance markets (e.g., Moll *et al*., 2008; Ayalew, 2008). While these studies assume all farmers to be homogenous in their preferences for non-tangible benefits, the method proposed primarily serves to account for such benefits in estimating the returns to a herd, while it is not used to estimate these benefits empirically.

More specifically, rural households in developing countries keep livestock to store wealth, as an insurance in the absence of formal insurance markets, and to improve their status (e.g., Moll, 2005; Moll *et al*., 2008); in addition to tangible financial objectives of using animals for draught power; manure production; and production of dairy and meat. As a consequence, in the absence of formal markets for insurance and financial services, utility derived from livestock is not only a function of its ‘dynamic’ productive value, but also of the static ‘keeping’ value.

The degree to which non-tangible benefits are important to farmers can further be related to their closeness to urban centres. In such areas, opportunities for intensified cash crop production are high, lowering the potential livestock densities as a consequence of reduced fodder supply from traditional fodder crops as mentioned above. More specifically, if livestock input markets such as for labour and fodder, and livestock output markets work perfectly, a farmer decides on efficient livestock production levels based on observed market prices. However, since markets for bulky organic biomass, such as crop residues, are usually fragmented and thin, even close to major urban centres, a farmer decides upon efficient livestock production levels and crop production jointly by implicitly calculating endogenous shadow prices of fodder products. Hence, the efficiency of integrating crop and livestock production depends on labour and land productivity in those crops that supply the mainstay of livestock fodder, in comparison to the productivity of alternative (cash) crops. As a consequence, a household with a relatively high labour to land ratio does not necessarily maintain more livestock than a household with a lower ratio, both of which may face labour market imperfections. Higher household labour resource availabilities could lead to a shift to more profitable, but more labour-intensive crop production such as vegetables. Expansion of cultivation of such cash crops close to urban markets would lower feasible livestock densities, and potentially the level of CLI, in the absence of non-tangible benefits associated with keeping livestock.

At the same time, formal financial institutions are commonly not well developed in rural areas, even in areas close to urban centres, thereby increasing the non-tangible benefits of keeping livestock from a wealth storage effect. For example, De Ridder *et al*. (2004) describe high livestock densities close to a major urban centre. As the authors argue, this may indeed reflect higher market opportunities for livestock products, but could also signal that livestock is used to store wealth, earned from crop or off-farm opportunities in the absence of formal financial services. Hence, such non-tangible benefits could be driving apparent high livestock densities in some locations, which in turn could incur higher levels of CLI.

5.3 Modelling livestock productivity

In this section we describe the techniques used to quantify tangible (Section 5.3.1) and non-tangible (Section 5.3.3) benefits of livestock production. In Section 5.3.2 we outline how the method described in Section 5.3.1 can be used in a farm household simulation model.

5.3.1 Quantifying tangible benefits from livestock production

The procedure to model livestock weight gain is based on the procedure used by e.g., Sissoko (1998), Savadogo (2000) and La Rovere *et al.* (2005), analysing crop-livestock farming systems in Mali, Burkina Faso and Niger, respectively. The analytical models used in all these studies make use of Equation (5.1). Equation (5.1) describes intake of organic matter as a function of the composition of feed offered. It is based on 831 samples from both tropical and temperate regions from feeding trials with sheep (Ketelaars and Tolkamp, 1992; Zemmelink *et al.*, 2003), but has been used for other types of livestock as well (e.g., Abegaz, 2005).

$$IOM = -42.78 + 2.3039*OMD - 0.0175*OMD^2 - 1.8872*N^2 + 0.2242*OMD*N \tag{5.1}$$

The calculation procedure applied relates feed on offer to potential liveweight change in two steps. In the first step, total Intake of Digestible Organic Matter (*IDOM*) as a function of the feed on offer is calculated. This is done by applying (5.1), in which the intake of organic matter (*IOM*) is calculated as a function of organic matter digestibility (*OMD*) and nitrogen content (*N*) of the feed on offer. It is thereby assumed that the crude protein content divided by 6.25 gives the nitrogen content in the feed source (FAO, 2004). Then, *IDOM* is obtained by multiplying *IOM* with organic matter digestibility (*OMD*). For the most common fodder types in the region, Table 5.1 describes the major characteristics based on Savadogo (2000) and Dada (1999).

Table 5.1: Characteristics of fodder types included

Fodder	Organic Matter content (% of dry matter)	Crude Protein content (% of organic matter)	Organic Matter Digestibility (%)
Maize	91 (87 - 95)	4.8 (4.6 - 6.5)	45 (40 – 55)
Sorghum	91 (90 - 94)	4.4 (2.8 - 7.0)	51 (43 - 65)
Millet	90 (89 - 93)	5.2 (4.8 - 9.3)	47 (29 - 63)
Cowpea	89 (88 - 92)	15.6 (13.9 - 21.7)	61 (58 - 74)
Groundnut	88 (85 - 90)	12.6 (8.5 -25.3)	57 (55 - 68)
Soybean	92 (91 - 94)	11 (7.6 - 13.3)	52 (43 - 63)

Average values of main characteristics of included fodder as reported by Savadogo (2000) are shown. Between brackets the minimum and maximum values are displayed. Data for soybean are from Dada (1999).

In the second step, the method described by Zemmelink *et al.* (2003) is used to estimate liveweight changes based on the Intake of Digestible Organic Matter. Total Intake of Metabolizable Energy (*IME*) is calculated from the metabolizable energy content of 15.8 kJ per g of digestible organic matter. Furthermore, since an animal requires 512 (kJ kg$^{-3/4}$ d^{-1}) *ME* to maintain its weight, the total feed quantities required to maintain an average animal at its initial weight can be calculated. Hereby, the weight to the power ¾ reflects metabolic weight, i.e., the weight of an animal less the weight of its bone material, which does not require energy for maintenance. Table 5.2 displays the annual feed requirements, expressed in quantities of fodder required, for a number of selected feed combinations.

Table 5.2: Annual feed requirements (kg dry matter year^{-1}) to maintain an average goat of 25 kg at initial weight based on selected (mixed) feeding strategies

Fodder type / Ration	Maize	Sorghum	Millet	Cowpea	Groundnut	Soybean
Maize (100%)	3360	0	0	0	0	0
Sorghum (100%)	0	3023	0	0	0	0
Millet (100%)	0	0	9467	0	0	0
Cowpea (100%)	0	0	0	1211	0	0
Groundnut (100%)	0	0	0	0	1488	0
Soybean (100%)	0	0	0	0	0	1634
Maize (50%) - Cowpea (50%)	917	0	0	917	0	0
Sorghum (50%) - Groundnut (50%)	0	886	0	0	886	0
Millet (50%) - Soybean (50%)	0	0	1505	0	0	1505

For selected feed compositions the Table shows the estimated quantity of feed required for maintaining an average goat (25 kg) at constant weight (ad libitum), calculated based on the method described in Section 5.3.1.

Based on these calculations, the fodder production resulting from crop production can be used to derive the herd size that can be maintained at constant weight. At this level of feed supply, however, weight gain and thus animal production could be realized for a smaller herd of animals, thus increasing the feed supply per animal above maintenance level. Similarly, in some cases a farmer might reduce feeding levels to below maintenance levels, thereby increasing the potential herd size. The latter situation will primarily occur if non-tangible benefits of keeping livestock are of great importance to a farmer.

To account for these possibilities in an LP-model (Section 5.4), the above-described calculation procedure is used to generate a sufficient number of input and output coefficients to reflect the most common feeding strategies. Hereby, in addition to the inclusion of identified rations at maintenance level, these rations are scaled to levels above maintenance, by multiplying feed quantities at maintenance feeding levels by 1.1, 1.2, 1.3, 1.4, and 1.5. Similarly, feeding levels below maintenance are incorporated, by multiplying maintenance feeding levels by 0.9 and 0.8. Hence, for each ration the intake of metabolizable energy at each of these feeding levels equals the intake at maintenance level multiplied by these scalars.

To further calculate the potential increase or decrease in liveweight of the animals, i.e., the output coefficients in an LP-model, we apply the procedure described by Zemmelink *et al*. (2003), in which the daily mean liveweight gain (*MLWG*) of an animal under consideration is given by:

$$MLWG = (IME - ME_M)/b \qquad (5.2)$$

Here, ME_M represent the daily maintenance requirements, expressed in metabolizable energy and conditional on the actual weight, while b denotes the metabolizable energy required per unit liveweight gain, set to 38.1 kJ g^{-1} (e.g., Abegaz, 2005). Total annual liveweight gain is then calculated by applying (5.2) for each day, whereby *IME* remains constant, but the daily maintenance requirements ME_M are adjusted to the new weight. Table 5.3 shows the liveweight of an average goat, with an initial weight of 25 kg, after one year, based on the different feeding levels included.

Naturally, livestock cannot be fed at levels below maintenance requirements for long periods. In our simulation approach we analyse a one-year period, for which the below maintenance feeding levels (0.8 * ME_M, 0.9 * ME_M) and associated weight loss (Table 5.3) are not unrealistic in a rural African setting.

Table 5.3: Final liveweight of an animal of 25kg initial weight at different feeding levels after one year

Feeding Level	0.8 * ME_M	0.9 * ME_M	1 * ME_M	1.1 * ME_M	1.2 * ME_M	1.3 * ME_M	1.4 * ME_M	1.5 * ME_M
kg	19.7	22.3	25.0	27.7	30.4	33.2	36.0	38.8

The table shows the weight of a ruminant of 25 kg after one year being fed at different feeding levels. The feeding levels are based on daily intake at maintenance level, multiplied by the shown scalar.

Finally, the quantities of organic matter that can be returned to the fields are included in the model by summing rejected feed and total manure produced. Rejected feed is estimated by taking the difference between offered organic matter and intake of organic matter. Manure production is obtained by subtracting the intake of digestible organic matter (*IDOM*) from the total intake of organic matter (*IOM*).

5.3.2 Livestock production in a programming-based household model

The procedure described in Section 5.3.1, describing the non-linear relationship between the identified rations, feeding levels and liveweight changes, can now easily be used to model livestock production in a linear farm household model. For this purpose, sufficient input and output combinations, based on different feeding options, are quantified and included in such a model (as illustrated by e.g., Sissoko (1998) and Savadogo (2000)). More specifically in this approach, the feed compositions in Table 5.2 define the feeding options and are further complemented with all possible pairs of fodder consisting of Maize, Sorghum, Millet, Cowpea, Groundnut and Soybean in different proportions (10% - 90%, 30% - 70%, 50% - 50%, 70% - 30%, 90% - 10%). These feed compositions are called the different rations, $r \in \{1, \ldots, R\}$. For each ration, the fodder quantities required at maintenance feeding level are estimated by applying the procedure as in Section 5.3.1. In addition, each ration can be fed at divergent feeding levels $f \in \{1, \ldots, F\}$, with associated weight losses or gains as defined in Table 5.3.

A farm household model[1] needs to be extended with extra constraints and identities (5.3, 5.4, 5.5) and a number of decision variables to account for livestock production. First, the decision variable AN_{rf} is defined as the number of animals allocated to feeding level f and ration r. The total number of animals allocated defines the total herd size H, as given by (5.3):

$$H = \sum_{r=1}^{R} \sum_{f=1}^{F} AN_{rf} \tag{5.3}$$

Based on this allocation, total fodder production can be estimated by (5.4 – left hand side), in which dom_{rfm} denotes the annual demand for fodder type m, when one animal is allocated to ration r and feeding level f. This total demand should be smaller than or equal to the total production of each fodder type, $TPD_{m.}$ The variable TFD_m directly results from the farm plan determined in the farm household model (see also Appendix B). It is thereby initially assumed that no fodder is sold or purchased at the

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[1] In this chapter the same mathematical programming model is used as in Chapter 3, to which the parameters, variables, equations and constraints discussed in Section 5.3.2 of this chapter are added. A description of the major features of this model is given in Chapter 3, while a full mathematical representation is included in Appendix B.

market, since little to no trade of fodder resources was observed in the region of study. For a more general treatment, this assumption can be relaxed.

$$\sum_{r=1}^{R}\sum_{f=1}^{F}(AN_{rf} * dom_{rfm}) \leq TPD_m \tag{5.4}$$

Finally, total liveweight production *TLG* is defined as in (5.5), in which lwg_f represents the annual increase in liveweight of an animal fed at feeding level *f* as displayed in Table 5.3. Furthermore, *TLG* can be multiplied by the market price of meat to obtain the total economic value of liveweight gain.

$$TLG = \sum_{r=1}^{R}\sum_{f=1}^{F} AN_{rf} * lwg_f \tag{5.5}$$

The above equations could be extended with a time subscript, to relate feed supply and liveweight change on a monthly base, but is not done in our approach. Hence, yearly feed supply is related directly to yearly liveweight changes, which is deemed appropriate since many farmers in the region of study harvest and store crop residues for controlled feeding during the rest of the year. Furthermore, the inclusion of a time subscript and including the above constraints for each month, is not likely to largely alter the optimal solution, if the total gain in liveweight, or its monetary value, is a component of the criterion function.

Finally, this procedure can be used to model production for different types of animals. This holds, because the maintenance energy requirements only depend on the liveweight of an animal, energy contents of the fodder on offer and the intake function (5.1). None of these characteristics is likely to change to large degrees for different types of animals (e.g., Ketelaars and Breman, 1991). In our approach, we express the total herd size as the number of small ruminants (e.g., goats), given the widespread ownership of small ruminants among smallholders in the region of study.

5.3.3 Quantifying non-tangible benefits of livestock keeping

The method outlined in the previous sections captures two important tangible benefits of keeping small ruminants to a smallholder, namely liveweight production and manure production. It does not yet however, capture the three main types of non-tangible benefits, i.e., (1) keeping livestock as insurance; (2) to store wealth in the absence of formal financial services; and (3) to display status.

In Bosman *et al*. (1997), Moll (2005) and Moll *et al*. (2008) an accounting procedure is used to calculate the value of both tangible and non-tangible benefits associated with livestock keeping. Total annual benefits B_t^k of keeping an animal, rather than selling it, is defined by (5.6):

$$B_t^k = Y_t^c + Y_t^k + B_t^s + B_t^p \tag{5.6}$$

Here, Y_t^c and Y_t^k reflect the net value of animal products, sold at the market and domestically consumed, respectively. In the analysis presented in this chapter, the value of animal products primarily stems from a gain in liveweight, since use of milk from small ruminants in the region of study is uncommon. B_t^s and B_t^p reflect the benefits from insurance and status, respectively, of keeping a herd. Moll (2005) proposes to quantify both as a fraction of the average market value of the herd (or animal), as given by (5.7) and (5.8).

$$B_t^s = b_t^s (P_t + P_{t-1}) / 2 \tag{5.7}$$

$$B_t^p = b_t^p (P_t + P_{t-1}) / 2 \tag{5.8}$$

Here, P_t represents the market value of an animal at time *t*. Moll (2005) argues that b_t^s generally takes values between 0.05 in locations without major weather risks, to 0.20 in more risk-prone areas. The main argument for such values is derived from comparing the cost of engaging in limited formal or informal local insurance with the total value of observed herd size. The status-fraction b_t^p, probably lies below the insurance value, as survival is more important than status. Nevertheless, higher values could reflect economically rational behaviour if herd size plays a role in acquiring local political or economic influence.

Furthermore, in addition to the benefits of keeping an animal as defined in (5.6), Moll (2005) defines non-tangible financing benefits as a fraction of the market price of an animal. This could, e.g., be seen as the cost foregone by not taking a loan or pawning assets alternatively. Moreover, savings accounts could be sensitive to inflation, while the real price of livestock is argued not to change much. We include such financing benefits similarly to (5.7) and (5.8) as a fraction of the average market value.

Hence, the total value of non-tangible benefits, $\pi_{NT,}$ is defined as a constant fraction *b*, of total average value of the herd in a year, as in (5.9). This is a slight simplification of (5.6) - (5.8), since we do not distinguish between the three separate components making up non-tangible benefits as outlined before. The main reason is that we are interested in the aggregate value of non-tangible benefits in the subsequent sections, while in an empirical analysis it would be impossible to identify the separate components when only herd size is observed.

$$\pi_{NT} = b(P_t + P_{t-1})/2 \tag{5.9}$$

$$\pi = \pi_C + \pi_T + \pi_{NT} \tag{5.10}$$

Now, total benefits to a farmer π are defined as in (5.10). In this definition, π_C represents total profit derived from crop income, π_T represents all tangible benefits of keeping livestock, such as total liveweight gain (5.5) multiplied with the market price of meat, as well as the value of manure production, the value of sold dairy products, and the value of used animal traction. In our analysis in Section 5.4, π_T consist of the value of liveweight gain only, while indirect benefits from using animal traction are accounted for indirectly in the profits derived from crop products, through reduced labour costs.

Clearly, if a farmer does not derive utility from non-tangible benefits of keeping livestock, i.e., the value of fraction *b* is zero, then a smallholder chooses a feeding strategy such that the total liveweight gain of the herd is maximized (i.e., $\pi = \pi_C + \pi_T$). On the other hand, if the smallholder mainly keeps livestock for non-tangible purposes, he/she chooses a feeding strategy such that the total average value is maximized (i.e., $\pi = \pi_C + \pi_{NT}$). In the former case a farmer typically maintains a smaller herd that is being fed at feeding levels above maintenance level (Figure 5.1, H_{A1}), while in the latter case a larger herd is kept close to, or even below, maintenance feeding level (Figure 5.1, H_{A2}).

This is further illustrated in Figure 5.1. Given a certain level of fodder production, a farmer has to select the size of his herd, thereby taking into consideration that for a smaller herd the tangible benefits are higher, but the consequence is that non-tangible benefits are lower. On the other hand, if the herd is larger, the tangible benefits are lower, but the non-tangible benefits higher.

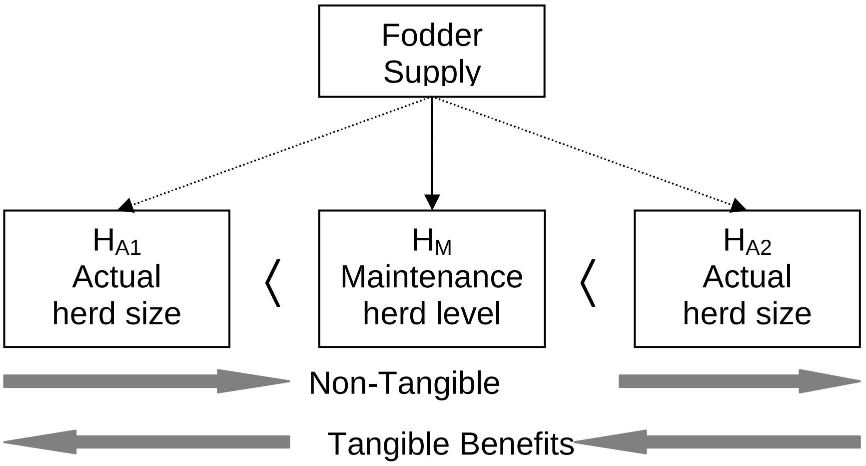

Figure 5.1: Choosing an efficient herd size. In the figure H_{A1} reflects a herd, that is smaller than the herd that can be kept at maintenance level, given a certain fodder supply. On the other hand herd H_{A2} reflects a herd being kept at levels below maintenance. Non-tangible benefits are highest in the latter situation, while smaller in the former. Tangible benefits are higher in the former, but smaller in the latter.

For example, a farmer maintaining a herd H_{A1}, which is smaller than can be kept at maintenance level H_M, is likely to place more value on liveweight production, or has recently faced a shock as a consequence of which he had to sell part of his herd, or faces other socio-economic impediments in raising his livestock level.

On the other hand, several factors may lead farmers to maintain a herd size H_{A2}, larger than can be fed at maintenance level, given their actual fodder production. For example, access to communal rangelands allows farmers to keep larger herds than based on crop residues solely. Therefore, it is necessary to correct for such factors increasing feed supply, after which the positive deviation of herd size from maintenance levels, i.e., (H_A-H_M) for $H_A > H_M$, is a good available method to estimate non-tangible benefits empirically, which is applied in Section 5.5. The above outlined procedures are used in the subsequent sections to quantify tangible and non-tangible benefits in a crop-livestock farming system.

5.4 Simulating crop-livestock integration

In this section we use a simulation model to analyse how levels of crop-livestock integration change under various scenarios. The model is based on a simulation model described in detail and used elsewhere (Chapter 3 in this thesis, Gerichhausen *et al.*, 2009), but extended with input- and output-coefficients to include liveweight production as explained in Section 5.2. In Sub-section 5.4.1 a number of important features of the applied simulation procedure are discussed, while the Sub-sections 5.4.2 and 5.4.3 describe the main simulation results.

The model is constructed from farm level data of 120 farmers in Ikuzeh, Hayin Dogo and Danayamaka in the Northern Guinea Savannah in Northern Nigeria collected in 2002 (see Figure 1.1 in Chapter 1). It has been solved for a one-year time horizon for two different criterion functions as explained in the next section. The choice of the one-year time horizon is motivated by the fact that yearly on-farm fodder production provides the mainstay of food for herds, with long-term storage of fodder being uncommon. Hence, a one-year time horizon is realistic for approximating feasible herd size.

5.4.1 Model

In the simulation approach applied, we determine efficient production strategies for all farmers, instead of for a representative group of farmers as done more commonly (e.g., Abdoulaye and Lowenberg-DeBoer, 2000). Because low computation times do no longer limit such simulations to a small group of representative cases, a main advantage is that patterns across simulation results can be determined, associated with differences in household characteristics. In this particular case we aim to determine how efficient levels of livestock density and manure availability –i.e., our proxies for CLI (see Section 5.1)– relate to land and labour availability, two of the most important resources of smallholder farmers in rural Africa.

The simulation model is solved for each individual farmer by adjusting farmer-specific parameters, which include farm and fadama size, household labour availability, household subsistence requirements, and availability of draught labour. Fadama’s are riverbed fields mainly used for cultivation of vegetables, sugarcane and rice. All other characteristics are assumed to be similar for each farmer. These are market prices, the crop and livestock production matrix, and nutritional values of the products. Similar to the approach followed in Chapter 3, a subsistence constraint is included to guarantee minimum nutritional consumption in a household. This must be attained first, after which the model maximises the respective objective functions as defined below. A full description of the model, the parameters, and their exact sources are given in Appendix B, while Sub-section 5.3.2 describes the specific adjustments made to include livestock production.

The simulation model is used to analyse how efficient herd size change under various scenarios. These scenarios are primarily based on different optimising strategies, reflected in different maximization objectives, whereby the utility derived from non-tangible benefits of keeping livestock is explicitly incorporated. In particular the simulation model is solved for two different objectives, after satisfying the subsistence constraint. The first objective is to maximize total profit (π_1) from crop production and non-tangible benefits of keeping livestock (5.11). In the second objective, the profit from crop production, the increment in liveweight, and non-tangible benefits are jointly maximised (5.12) as ‘overall’ profits.

$$\pi_1 = \pi_C + \pi_{NT} \tag{5.11}$$

$$\pi_2 = \pi_C + \pi_{NT} + \pi_T \tag{5.12}$$

5.4.2 Optimising profits with non-tangible benefits.

Table 5.4 lists some of the main results from the simulation model under the two different objectives, profits π_1, and ‘overall’ profits π_2, included. Results are differentiated according to the two different assumptions of the non-tangible benefits parameter *b* as defined in (5.9). First, this parameter is set to 0.25, in line with the approximations as in Moll (2005). Second, the parameter is increased to 0.5 to analyse the effects of an increase in the importance of non-tangible benefits of keeping livestock.

Table 5.4: Average results from the simulations for different objectives and changing preferences for non-tangible benefits of keeping livestock

Objective Function:		π_1		π_2	
Parameter of non-tangible benefits:		0.25	0.50	0.25	0.50
	Unit				
Share of profits from crops in total	%	98.88	97.77	99.11	98.79
Share of profits from liveweight in total	%	0	0	0.56	0.56
Share of non-tangible benefits in total profit	%	1.12	2.23	0.33	0.65
Average profit	USD ha^{-1}	584	589	581	582
Supply of organic matter	kg ha^{-1}	276	278	150	150
Average herd size	TLU ha^{-1}	0.049	0.050	0.006	0.006

When a farmer strives to maximize profits from crop production and non-tangible benefits (π_1), in 74 out of the 89 cases it is efficient to maintain a herd size below maintenance level (data not shown). For no farmer this is an efficient strategy if overall profits are maximized (π_2). Hence, as can be seen from Table 5.4, an efficient farmer chooses the smallest but most productive herd size if overall profits are maximised. When objective π_1 accurately reflects the farmer goals, the actual weight loss (i.e., $\pi_T < 0$) is not included in the objective. Therefore, π_1 is on average higher than in the case in which both tangible and non-tangible benefits are maximised (π_2). In addition, Table 5.4 shows that supply of organic matter on the farm, by combining rejected feed and manure production, correlates to herd size. Since herd size depends on the exact structure of the objective function, as well as on the magnitude of preference for non-tangible benefits (expressed in *b*), the supply of organic matter also depends on these factors.

Note that the herd size, the share of tangible livestock benefits and the share of non-tangible benefits of livestock are all low. These mainly result from the dominance of high-value crops in many of the simulation results. The inclusion of different production attributes such as risk aversion, similar to the approach followed in Chapter 3, may therefore better represent actual farmer decision-making. To do this, however, is outside the scope of the present study,

To further illustrate how herd size differs across different farms, we categorise farmers according to their two most important assets, farmland and household labour. Figure 5.2 shows the simulated relationship between labour availability for crop production and the efficient herd size both expressed per hectare, for the two objectives. Quadratic trend lines are plotted, displaying a slightly better fit than linear trend lines. Herd size is generally observed to be largest when a farmer strives to maximize profits from crop production and non-tangible benefits from livestock (π_1). Maximisation of overall profits leads to the smallest herd size per hectare, as argued a reasonable proxy for the degree of crop-livestock integration.

The relationships in Figure 5.2 are however somewhat distorted by different village effects. This is due to particular differences in the village-level production matrices included in the simulation model. We therefore plot the effects for the individual villages and again plot a quadratic trend line. Figures 5.3 and 5.4 display the results for two of the three locations. These figures suggest that efficient herd size follows an inverse U-shaped pattern in relation to labour availability per unit of cropland.

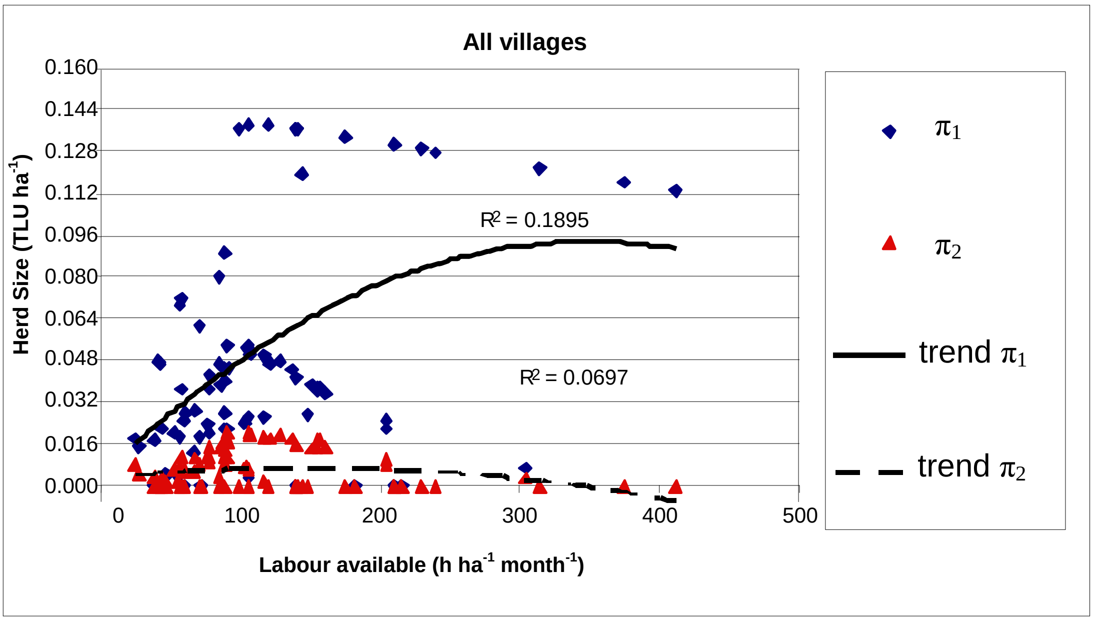

Figure 5.2: Simulated efficient herd size in all villages as a function of labour availability. The figure shows results for a scenario in which profits from crop production and non-tangible benefits from keeping livestock are optimised (π_1) and a scenario in which profits from crop production, liveweight production and non-tangible benefits are optimised (π_2). The parameter *b*, reflecting non-tangible benefits as in (5.9), is set to 0.25.

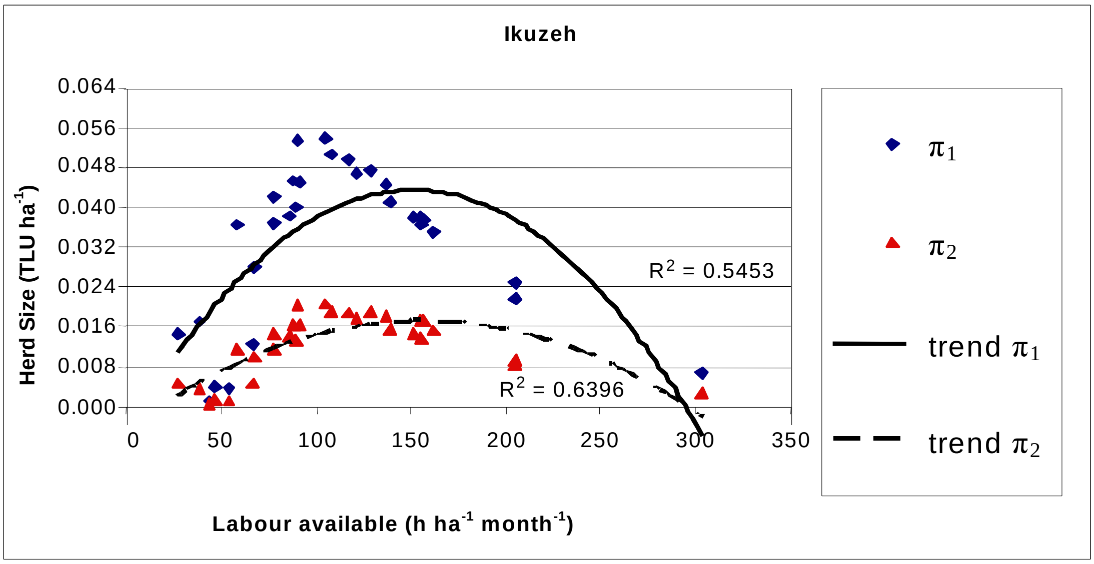

Figure 5.3: Simulated efficient herd size in Ikuzeh as a function of labour availability. Scenarios π_1 and π_2 are similar to those in Figure 5.2.

The inverse U-shaped pattern observed in most cases relates directly to the differences in cropping patterns selected along the labour to land continuum as illustrated in Figure 5.5. First, at low levels of labour availability, the efficient cropping pattern consists mainly of cereals, to meet subsistence food demands and a small portion of high-value crops for additional purchase of food crops and other needs.

Second, when labour becomes relatively more abundant, it becomes economically more attractive to cultivate legumes, which are more demanding in labour, and thereby provide high quality fodder, an option to increase herd size. Finally, at still higher levels of labour availability, it becomes more attractive to switch back from cultivating legumes to high-value crops. Consequently, fodder production decreases again and efficient herd size decreases. These findings are summarized in Table 5.5.

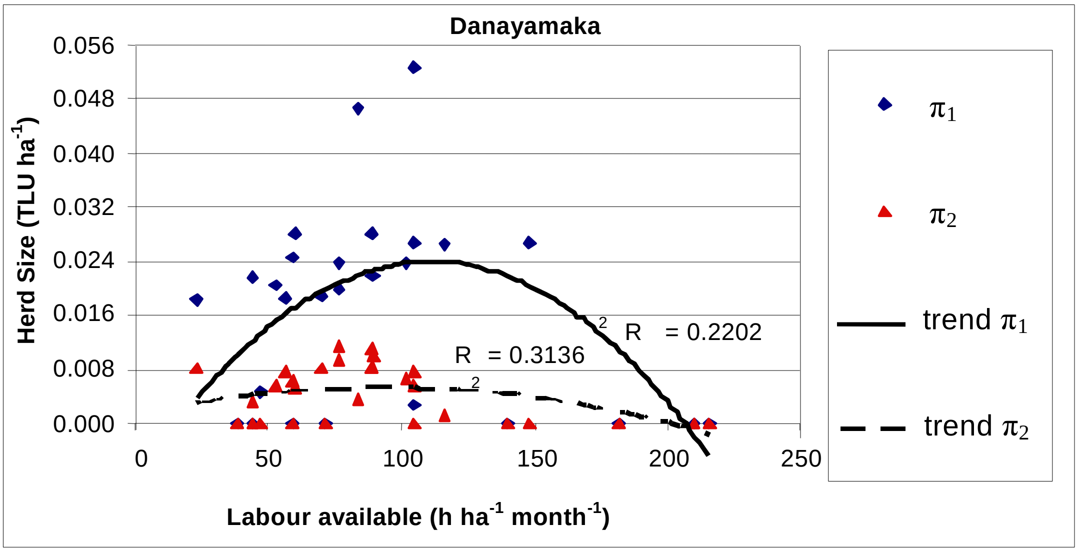

Figure 5.4: Simulated efficient herd size in Danayamaka as a function of labour availability. Scenarios π_1 and π_2 are similar to those in Figure 5.2.

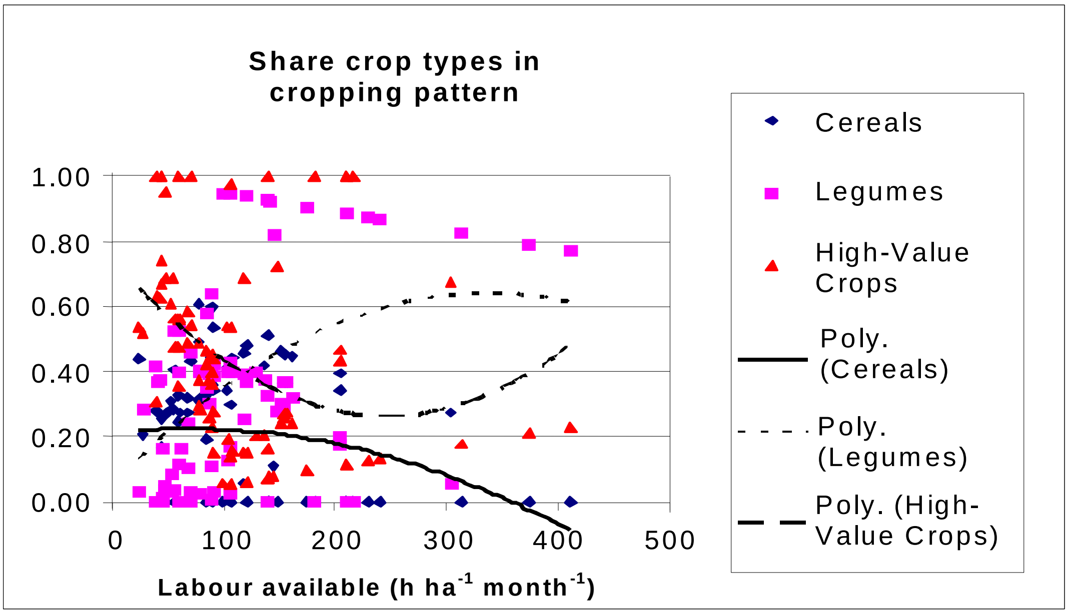

Figure 5.5: Simulated share of revenue per crop types in total revenue in Ikuzeh as a function of labour availability.

Table 5.5: Simulated efficient levels of crop-livestock integration

	Labour per unit of cropland available L (h ha^{-1} $month^{-1}$):		
	Low L <100	Intermediate 100 < L <200	High >200
Cropping Pattern[1]	High Value crops > Cereals = Legumes	Legumes > High Value crops > Cereals	High Value crops > Legumes > Cereals
Herd Size[2] (TLU ha^{-1})	0.019 (0.006 - 0.032)	0.038 (0.008 - 0.068)	0.031 (0.001 - 0.061)
Manure production[2] (kg ha^{-1})	342 (158 - 504)	395 (145 - 641)	341 (22 - 692)
Level of Crop-Livestock Integration:	Low	High	Low

[1] *Order reflects importance of crop type in total revenue*

[2] *The average herd size and manure production are the averages from the different simulated strategies. The values in brackets are the averages of the minimum and maximum values*

5.4.3 Changing non-tangible benefits.

Non-tangible benefits of keeping livestock are included by setting the parameter *b*, expressing the total value of non-tangible benefits as a fraction of the total average herd value, at 0.25 as based on the rough estimates used by Bosman *et al.* (1997), Moll (2005) and Moll *et al.* (2008). We subsequently increase the value of this parameter to analyse how average herd size changes when non-tangible benefits become relatively more important. Table 5.6 displays the average herd size (taken as the average herd size resulting from π_1 and π_2 respectively). The results show that herd size is relatively insensitive to the relative value attached to non-tangible benefits. At low to moderate levels of labour availability, increases in *b* lead to small increases in herd size, mainly since non-tangible benefits represent a relatively large proportion of total net benefits. At high labour availability, non-tangible benefits are negligible compared to total net benefits.

Table 5.6: Efficient herd size as a function of relative preference for non-tangible benefits

		Value of non–tangible Benefits parameter b:				
Labour availability:		0.25	0.50	0.75	1.00	2.00
L <100	Herd Size:	0.019	0.019	0.020	0.021	0.021
100 < L < 200	(TLU ha^{-1})	0.038	0.038	0.039	0.041	0.041
L > 200		0.031	0.031	0.031	0.032	0.032

The simulation results suggest an inverse U-shaped relationship between labour availability and herd size. Furthermore, the results show that the impact of changes in parameter *b* on the optimal herd size is low, however this impact also depends on the form of the criterion function used. Moreover, the preference for non-tangible benefits may not be similar for different farmers. Therefore, deviations in herd size, as a result of household specific preferences for non-tangible benefits, are estimated in Section 5.5.

5.5 Statistical Analysis

The objective of the analysis in this section is to illustrate the method to quantify non-tangible benefits of keeping livestock as introduced in Section 5.3.3. Secondly, the analyses allow us to compare the patterns of CLI, observed in the simulation model (Section 5.4), with farm-level observations on CLI.

In Sub-section 5.5.1 we discuss some key observations, such as actual livestock holdings and variations in cropping patterns in the data used, as well some of the main limitations. Secondly, we use econometric analysis to identify the variables that cause the observed variations in the levels of crop-livestock integration. To this effect we identify factors in Sub-section 5.5.2 that lead farmers to deviate from keeping a herd at maintenance levels, in Sub-section 5.5.3 factors leading to differences in manure use at farm level, while in Sub-section 5.5.4 we identify factors leading to variations in cropping pattern.

5.5.1 Data description

In the statistical analysis in this sub-section we use farm-level data from 250 farmers in Northern Nigeria, collected in seven villages in 2007 in different agro-ecological zones (see Figure 1.1 in Chapter 1), including the villages Ikuzeh and Hayin Dogo displayed earlier in this chapter. The data set includes information on plots owned and cultivated, selected cropping patterns and input use, as well as various data on household composition and asset ownership.

Table 5.7 shows averages in livestock ownership across the different surveyed locations. The table shows that while ownership of poultry, donkeys and pigs is fairly homogenous, there are considerable differences across the locations in ownership of the other livestock types. However, higher levels of e.g., bull ownership are associated with higher levels of small ruminant ownership as well. Therefore, even though the roles of both types of animal are different, i.e., bulls mainly provide animal traction and goats are mainly kept for manure production, total levels of crop-livestock integration are likely to be captured reasonable well by the aggregate measure of livestock ownership per unit of cropland.

For a number of these locations Figure 5.6 shows the relationship between actual herd size and household labour available to agriculture per unit of cropland, while the relationship is similar for the locations not shown. A quadratic trend line is plotted for each location. Bindawa is located, rather isolated, on the edge of the Sahel and Soudan Savannah zone, Warawa is located close to the major metropolis Kano in the Soudan Savannah, while Ikuzeh is a location in the Northern Guinea Savannah (see Figure 1.1 in Chapter 1).

Table 5.7: Ownership of livestock types across the region of study

	Average livestock ownership per type (TLU ha^{-1})							
Location	TLU	Cattle	Bulls	Goats	Sheep	Poultry	Donkeys	Pigs
Kaita	0.50	0.11	0.16	0.15	0.02	0.03	0.03	0.00
Bindawa	0.52	0.13	0.24	0.07	0.04	0.02	0.02	0.00
Kunchi	1.23	0.37	0.36	0.23	0.17	0.07	0.04	0.00
Warawa	0.31	0.07	0.04	0.07	0.07	0.02	0.03	0.00
Kiru	0.45	0.00	0.10	0.20	0.07	0.07	0.01	0.00
Hayin Dogo	1.69	0.44	0.91	0.13	0.14	0.07	0.00	0.00
Ikuzeh	0.20	0.07	0.00	0.06	0.00	0.04	0.00	0.03
All	0.76	0.19	0.30	0.12	0.07	0.05	0.01	0.01

Tropical Livestock Units in this table, and elsewhere throughout Section 5.5, are calculated by using the following conversion factors: Cattle/Bull = 1 TLU; Goat = 0.08 TLU; Sheep = 0.1 TLU; Poultry = 0.01 TLU; Donkey =0.5 TLU; Pig = 0.2 TLU.

The observed inverse U-shaped pattern in Ikuzeh appears to resemble the simulation results (the pattern in Hayin Dogo is similar, data not shown). This pattern is robust to removing one or several potential outliers with very high labour availability. Hence, at low levels of labour availability per unit of cropland, increased labour availability allows for increasing the herd size that can be maintained efficiently. However, this does not occur at the highest levels of labour availability.

On the other hand, the relationships in other locations, including those not shown in Figure 5.6, suggests a weakly increasing relationship. An important reason for this difference could be the lack of high-value alternatives such as vegetables in the more arid locations in the Soudan-Savannah and the Sahel. Hence, even at the highest levels of labour availability per unit of land, the efficient cropping system consists of a combination of cereals and legumes.

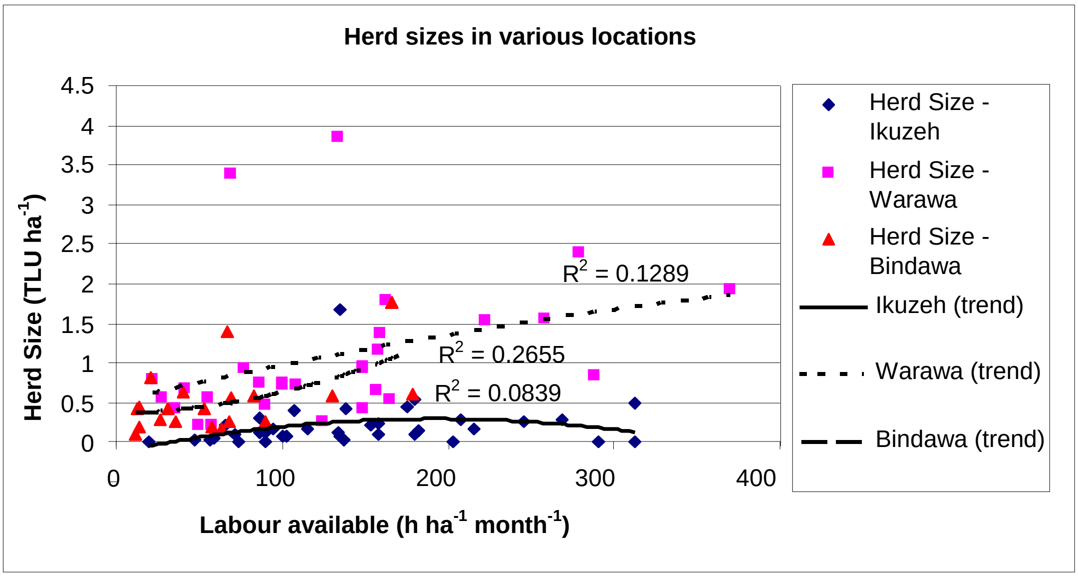

Figure 5.6: Observed herd size in relation to labour availability

Figure 5.7 displays the actual share of vegetables in total revenue, as well as the shares of legumes and cereals for all farmers in the region. Three quadratic trend lines are plotted in the figure that suggest a similar pattern as in the simulation results.

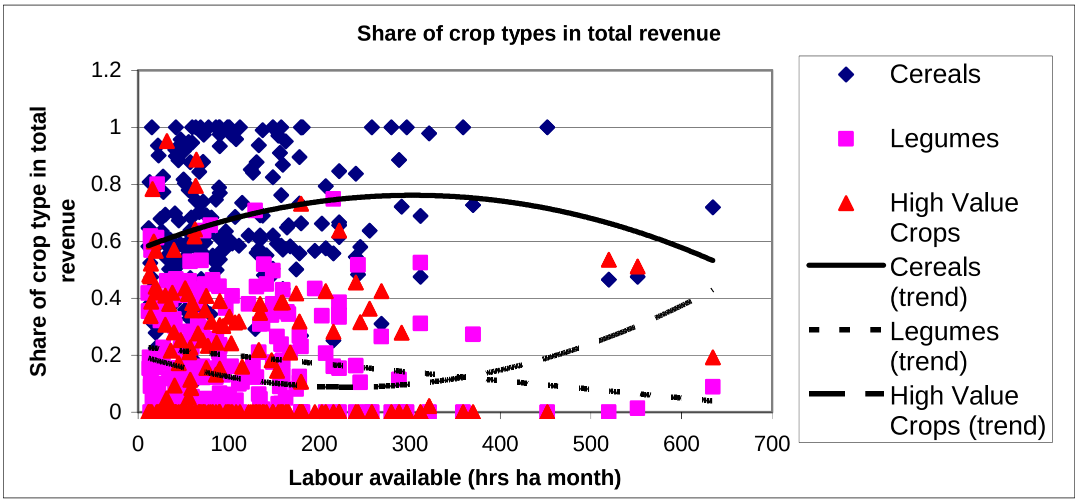

Figure 5.7: Observed share of crop types in total revenue in relation to labour availability.

However, linear trend lines suggest an overall increasing share of cereals and overall decreasing shares of legumes and high value crops with increasing labour availability. However, these trend lines should be interpreted cautiously, as clearly the fit is very low, and strongly influenced by a few observations with high labour availability per unit of cropland. The most important observation from this figure is that the relationship between land and labour availability and the cropping pattern selected is weak at best, so that most likely additional factors also play a role.

Finally, Figure 5.8 shows the distribution of the difference between actual herd size and herd size estimated from feed requirements at maintenance level. This difference is calculated by determining 'maintenance herd size H_M' for each farmer, based on actual production, following the method described in Sub-section 5.2.1, and subtracting this value from actual herd size H_A. Again, similarly to the simulation approach in Section 5.4, we express both actual and simulated herd size in number of goats without loss of generality. Actual herd size is derived by using standard conversion factors for Tropical Livestock Units (TLU) (FAO, 2004a). Actual fodder production is derived from observed grain production by using the statistical relationships estimated by Savadogo (2000) for Burkina Faso.

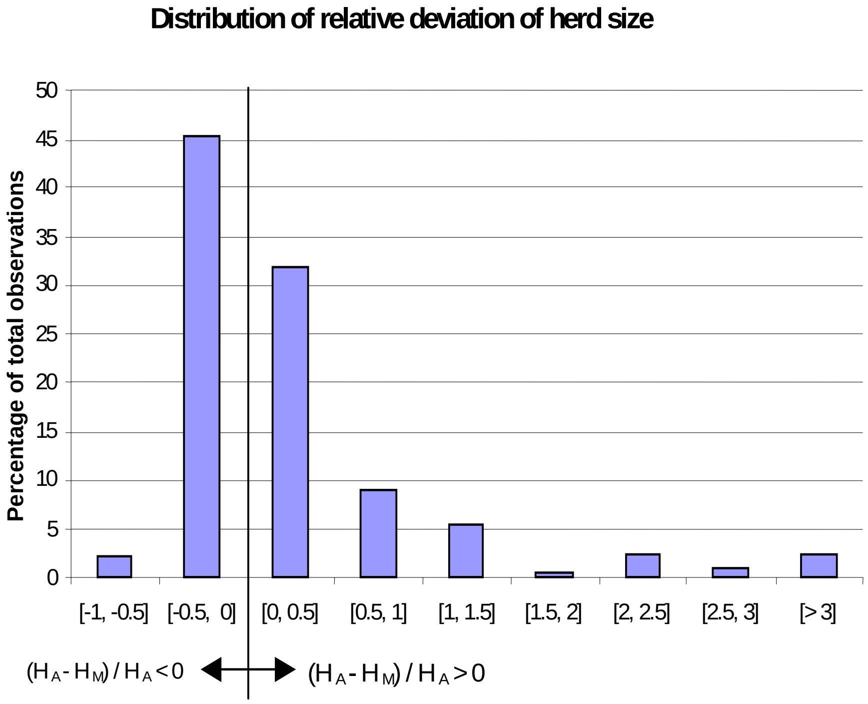

Figure 5.8: Deviation of actual herd size from 'maintenance herd size' (see text for explanation). The figure displays the distribution of the difference between actual herd size and estimated maintenance herd size, expressed in number of goats per hectare of farmland.

Figure 5.8 shows that 47% (of 201 observations) of farmers maintain herd size smaller than maintenance herd size (i.e., H_A - H_M < 0), at given levels of on-farm fodder production. For the remaining 53% herds are too large, i.e., exceeding the herd size that can be maintained given on-farm fodder production (i.e., H_A - H_M > 0). These observations are different from the outcomes of the simulation models, where non-tangible benefits only appeared to play a minor role. On the other hand, unobserved village characteristics such as access to grazing resources, could partially explain the results in Figure 5.8.

Emphasis in the analysis in this section is placed on illustrating the workings of a novel method to empirically estimate non-tangible benefits, while acknowledging that the data set used poses a number of limitations. A number of farm characteristics that are likely to affect the results, are missing in the data set.

First, as mentioned earlier, households may have recently faced an idiosyncratic shock and therefore put the insurance value of their herd to work. This would suggest the actual herd size is lower than the historic average. This issue can only be addressed by developing a panel data set, which was not possible within the scope of the current research project and is left to other researchers.

Second, feed quantities are based on stated crop production quantities. This may in fact be an underestimate of real feed supply, since farmers either may have purchased additional feed resources, or may have acces to significant grazing resources are in their vicinity. Informal discussions with farmers in the region led us to conclude that trade in crop residues played only a minor role in the rural areas, contrary to the situation for urban livestock farmers, while a grazing reserve only exists close to one of the locations surveyed (Kaita). We have assumed that all farmers have equal access to this reserve, which can then be accounted for by including a village dummy in the analysis. The impact of these unobserved variables is discussed where appropriate in the remainder of this chapter.

5.5.2 Factors affecting preferences for non-tangible benefits

Figure 5.8 suggests a considerable number of farmers having a herd size that is ‘too large’, i.e., being fed below maintenance level. In this section we identify the variables that lead farmers to maintain such “too large” herds, thus suggesting derivation of substantial utility non-tangible benefits. We subsequently estimate the model described by (5.13) and (5.14) (suppressing the farmer subscripts) by applying a Heckman selection model (e.g., Verbeek, 2000).

$$y = \sum_{i=1}^{N} x_i \beta_i + \varepsilon_1 \qquad (5.13)$$

$$w = \sum_{i=1}^{N} x_i \beta_i + \varepsilon_2 \qquad (5.14)$$

Equation (5.13) is only estimated for positive deviations. Therefore Equation (5.14) is included to describe factors leading a farmer to select a herd that is “too large”. In the analysis, the dependent variable w is defined as $w = 1$, for $y > 0$, and $w = 0$ otherwise. Finally, x_i represents a set of variables, assumed to be exogenous to herd size deviations, which includes farm and household size, age, education level, and income from remittances and/or off-farm activities.

By using this approach we allow some variables to influence the magnitude of the deviation, but not the probability of a farmer deviating from maintenance levels and vice versa. For example, the absence of formal and informal credit facilities in one location affects all farmers in that location, and could increase the likelihood that livestock is kept for financing or wealth storage. However, the magnitude of the deviations may vary among farmers due to personal characteristics such as access to off-farm income.

Furthermore, we estimate two different models (Models A and B, Table 5.8) for two different dependent variables y in (5.13). In Model A, the deviation from maintenance levels, $y = H_A – H_M$, is taken as dependent variable, in Model B, the relative deviation, $y = (H_A – H_M)/H_A$.

The results of the selection model (lower part of Table 5.8) suggest that specific village characteristics, such as local access to financial resources, market outlets, and the occurrence of village-specific shocks indeed do influence the likelihood of having a ‘too large’ herd. The village dummies for which no significant effects were found are removed from the final regressions to increase the efficiency of the estimation. The set-up of the included dummies is such that the village of Kaita is the reference, while in most other locations the likelihood of having a ‘too large’ herd is smaller. This is not surprising as the village of Kaita is the only location where communal grazing resources have been observed. Unfortunately, the exact village characteristics that play a role are difficult to identify.

Furthermore, farm size and household size significantly influence the probability of having a positive deviation, but neither of these variables significantly affects the magnitude, either absolute or relative, of the deviation. The signs of both variables are similar to those observed in the simulation model.

Table 5.8: Regression results: determinants of crop-livestock integration

	Model	A	B	C	D
	Dependent Variable	Herd size deviation	Relative herd size deviation	Total manure use	Average manure use per ha
Equation 12	Variable	Coefficient	Coefficient	Coefficient	Coefficient
	Constant	-11.54*	4.66	6324	1268
	Farm size (log)	0.42	-0.45	-1282	-541***
	Farm size (log squared)			627	
	Household size (log)	0.40	-0.43	-3848	261*
	Household size (log squared)			1449*	
	Livestock ownership (TLU) (log)			930***	186**
	Average soil quality of fields (1 = poor, 2 = average, 3 = good)	-3.18	-3.16**	-3707**	-546
	Achieved primary or koranic education (dummy)	2.35**	1.22	782	206
	Achieved secondary education or higher (dummy)	1.87	1.04	2451*	443
	Receives remittances (dummy)			1675*	-4
	Share of household members having access to off-farm income			-3799**	-652*
	Age household head	3.08*	0.22		
	Average age household members	3.46**	0.20	699	94
	Kunchi village (dummy)	4.90***	1.60*		
	Hayin Dogo village (dummy)	0.42	-0.45		
	Warawa village (dummy)			3725***	578***
	Ikuzeh village (dummy)				-456
Equation 13	**Selection model:**				
	Variable	Coefficient		Coefficient	
	Constant	-0.28		-2.62**	
	Farm size (log)	-0.47***			
	Household size (log)	0.56***			
	Livestock ownership (TLU) (log)			0.13	
	Average soil quality of fields (1 poor, 2 average, 3 = good)	0.70			
	Achieved primary or koranic education (dummy)	-0.15		0.47	
	Achieved secondary education or higher (dummy)	0.10		1.23***	
	Average age household members	0.77*		1.24***	
	Kunchi village (dummy)	-0.75***		-0.88**	
	Warawa village (dummy)	-1.28***		-1.00***	
	Kiru village (dummy)	-1.43***		-1.13***	
	Hayin Dogo village (dummy)			-2.66***	
	Ikuzeh village (dummy)	-0.47***		-2.17***	

** significant at 10%, ** significant at 5%, *** significant at 1%*

A larger household, all other variables being equal, increases the likelihood of a too large herd. Two possible reasons may explain this finding. First, the availability of more labour allows managing a larger herd more effectively. Second, overall higher income in larger households allows for (unobserved) purchase of additional feed.

In the next section we will observe that large households are more likely to cultivate high-value crops, giving credence to the latter argument. Moreover, higher incomes resulting from high-value crops need to be stored, which in the absence of financial markets is easily done by buying livestock. However, access to remittances or off-farm income has no influence. Finally, the effect of household size could suggest that larger households keep more livestock because more people need to be insured.

On the other hand, the likelihood of keeping a ‘too large’ herd is negatively correlated, ceteris paribus, with farm size. Again, with decreasing labour availability per unit of cropland, the likelihood of cropping high-value crops decreases. Moreover, a larger farm size allows for higher subsistence production, thereby lowering the risk of failing to meet subsistence requirements, and lowering the need to insure such risks by keeping livestock.

The actual size magnitude is neither related to village characteristics, except for Kunchi village, nor to farm and household size. The magnitude of the deviation is affected by the age of the household head and the average age of the household members. This is not surprising, as older farmers may have accumulated more wealth over time, which in the absence of formal financial services is stored in livestock. Furthermore, completion of primary education increases the magnitude of the deviation from maintenance levels, but the underlying reason for this relationship is not intuitively clear.

The results in the second column, explaining the deviation in percentages of herd size, present a different picture. The age and education effects are no longer significant, while there is a significant effect from the quality of fields owned. When fields are more fertile, herd size deviations are smaller. This could point to a risk effect, whereby more fertile fields give higher and more secure yields, and the need to maintain a larger herd for insurance purposes declines.

5.5.3 Factors affecting manure use

An important component of crop-livestock integration is the use of manure. Moreover, the simulation models in Section 5.4 suggest optimal herd size changes due to changes in cropping patterns, and manure production changes in the same direction as herd size. Hence, variables affecting positive deviations in herd size are expected to influence the use of manure as well. Therefore, in this section we determine variables affecting the likelihood of a farmer using manure on his farm, as well as factors determining the quantity of manure used. The model is similar in set-up to (5.13) and (5.14), but y now represents total use of manure in kg, while the dummy variable $w = 1$, if a farmer uses manure in his farm, and $w = 0$ otherwise. The results are also shown in Table 5.8, whereby the dependent variable in the third column is total use of manure (kg) (Model C) and the fourth column the average use of manure (kg/ha) (Model D). Note again that the selection model is the same for both dependent variables.

In the selection component of the model, large differences are again observed among locations. Furthermore, total herd size does not play a significant role in determining whether or not a farmer uses manure. Further inspection of partial correlations (data not shown) shows that use of manure correlates strongly to ownership of small ruminants, but not to other livestock types. Clearly, small ruminants can be confined, and the manure can be collected more easily. A further explanation for the low overall correlation between herd size and manure use could be that the reported use of manure does not distinguish between the use of actual animal manure and compost from urban and other household waste. Personal observations suggest that these additional sources of organic material are used more frequently in Warawa village close to Kano.

Larger household size, more education, and access to remittances all positively affect the quantity of manure used. While more labour allows for more effective application of manure, remittances allow for additional purchases of manure and/or for paying for costly and labour-intensive transport of manure to fields. This observation could suggest that remittances are partially invested in improving soil fertility resources.

On the other hand, a reported high quality of the fields and a high share of household members engaged in off-farm jobs, negatively affect the quantity of manure used, but not the likelihood of using manure. While applying manure at relatively rich fields may yield lower returns to labour, the labour devoted to off-farm income limits the labour availability to manure application.

5.5.4 Factors affecting cropping patterns

The primary interest of the analysis in this final sub-section is to identify how important indicators of crop-livestock integration, livestock ownership and manure use affect production and crop choice. The simulation results in Figure 5.5 show that at high labour availability per unit of cropland, the contribution of both cereals and legumes in total revenue declines, while the contribution of high-value crops increases, similar to the simulation results found in Sub-section 5.4.2. A number of regressions is carried out to test for the presence of this relationship in the data.

Again, these estimations are based on the structure of the selection model described by (5.13) and (5.14), and the results are shown in Table 5.9 (Models E - L). The inclusion of (5.14) as a selection equation, with $w = 1$ if the crop type is cultivated, and $w = 0$ otherwise, allows for the identification of factors affecting the likelihood of cultivating a certain crop type, which could differ from factors affecting the produced quantities. However, since all farmers cultivate cereals (for subsistence production), no selection model is estimated for this crop type (Models E, F, H, I, Table 5.9).

Moreover, for each crop type, i.e., cereals, legumes and high-value crops, two different specifications are estimated. These specifications differ in the dependent variable y (Equation 5.13), whereby the first specification (Models E, F, G, H, Table 5.9) assumes the share of the crop type in total revenue as dependent variable. The second specification (Models H, I, J, K, Table 5.9) takes the revenue per crop type divided by total farm size as dependent variable. The effect of exogenous variables is expected to be largely similar in both specifications, though the second specification better captures how exogenous variables affect agricultural intensification per unit of farm size.

Both dependent variables are a function of (1) semi-fixed variables affecting both the crop selection and production quantities; (2) semi-fixed variables solely affecting selection and (3) input variables directly affecting production. This is also indicated in the second column in Table 5.9. Variables in the first category are household labour and farm size both influence both production quantities, being productive inputs, as well as the crop mix through household subsistence food preferences. The second

Table 5.9: Regression results: what determines cropping patterns

		Dependent variable:	*Share of crop type revenue in total revenue*				*Revenue of crop type per hectare*			
			Cereals	Cereals	Legumes	High Value Crops	Cereals	Cereals	Legumes	High Value Crops
		Model:	E	F	G	H	I	J	K	L
		Estimation method:	Tobit	IV-Tobit	Heckman	Heckman	OLS	2SLS	Heckman	Heckman
		Prob > chi^2	0.000	0.005	0.02	0.0002	0.000	0.000	0.000	0.001
		Adj. R^2	n.a.	n.a.	n.a.	n.a.	0.69	0.68	n.a.	n.a.
Eq. 12	Type[1]:	Variable Name[2]:								
	(1)	Farm Size (ha)	-0.018	0.005	-0.006	-0.027	1,856**	-198	-381	-16,630
		Farm Size squared (ha)	0.000	0.000	0.000	0.001	-55	0	8	411
		Household Size (#)	-0.011	-0.020	-0.007	0.068**	544	-143	-235	58,376**
		Household Size squared (#)	0.001	0.001	0.000	-0.004**	-47	12	18	-2,965*
	(2)	Livestock ownership (TLU/ha)	0.041**	0.028	-0.003	0.054	4,905***	794	1,046*	20,137
	(3)	Fertilizer use (kg / ha)	-0.001**	0.000**	0.000	0.001**	135***	31***	38***	870***
		Hired Labour use (hrs / ha)	-0.037	0.012	-0.019	-0.148	18,744***	1,379*	1,527**	-95,064**
		Pesticide use (ltr / ha)	-0.103**	-0.012	0.000	0.084*	-1,037	659	421	-13,690
		Manure use[3] (kg / ha)	0.000	0.000*	-0.006	0.000	-2	0	-1	-40
Eq. 13		Selection Model:								
		Farm Size	n.a.	n.a.	0.05**	0.72**	n.a.	n.a.	0.05**	0.72**
		Household Size	n.a.	n.a.	0.07	-0.02	n.a.	n.a.	0.07	-0.02

*The table displays factors determining the share of a crop type in total farm revenue, and factors determining the revenue per hectare for each crop type. Thereby the following significance levels are included: * significant at 10%, ** significant at 5%, *** significant at 1%.*

[1] *(1): semi-fixed variables, which directly affect production quantities and crop choice; (2) semi-fixed variables, which only affect crop choice; (3) input variables, which only affect production quantities*

[2] *Village dummies and constants were included in the separate regressions, but omitted from the table for clarity.*

[3] *Manure use is instrumented for in Model F and J by 'distance to markets' to correct for large measurement errors in use of manure (first stage regression not shown)*

category contains livestock ownership, inducing a demand for fodder crops and hence influencing the crop selection. Finally, use of hired labour, fertilizer, manure and pesticide, increase the dependent variables, but not necessarily in the same way for each crop type as inputs may be applied selectively.

The regression with the share of cereals as dependent variable is done with a Tobit regression censored at 1 (Model E). In this way we correct for the bias due to the right censoring of the dependent variables at 1, which occurs in a number of cases when a farmer only cultivates cereals. The regression for cereal revenue per hectare is done with OLS (Model I).

The consistency of the estimation may further be affected by the inclusion of manure application per hectare. The inclusion of both livestock ownership and manure in the regression should allow for identification of the specific effects of both variables, i.e., an increase in demand for fodder products, and an increase in production through fertilization, respectively. However, the collected data on manure use likely suffer from measurement errors. Total manure use is estimated by converting the recorded number of donkey loads, wheelbarrows and/or local carts applied into weight, by using measurements from IITA research facilities. Hence, the resulting quantity is still a rough estimate.

Manure use correlates strongly to ownership of small ruminants, but this variable also directly affects the crop selection, and by consequence does not qualify as a good econometric instrument. Manure use does also correlate (negatively) with distance to the nearest market, but this variable is largely the same for farmers in one particular location, and considerable within-village variation is lost in an instrumented variable approach. Still, a first stage regression of ‘manure use’ on ‘distance to market’ passes the rule-of-thumb for a strong instrument (Stock and Watson, 2003). For all specifications and crop types an instrumented variable approach is deployed, though only in the case of cereals weak significant effects of manure use are identified (Models F, J, Table 5.9). The regressions shown for the other crop types are therefore the uncorrected versions.

Moreover, an endogenous relationship between the dependent variables and the variable inputs fertilizer and hired labour may exist. This is likely to occur when use of both inputs strongly correlates to weather outcomes, which are not included in the specification but captured in the error term. Unfortunately, no strong instruments for fertilizer and hired labour are available. A Durbin-Wu-Hausman test based on value of assets as an instrument for hired labour, albeit a weak one, does not suggest hired labour to be endogenous. Hence, no further endogeneity correction is pursued for these variables.

The results show that an increase in farm size increases the revenue of cereals per hectare (Model I), but this effect disappears after correcting for the measurement errors in manure use (Model J). At the same time, an increase in farm size increases the likelihood of a farmer cultivating legumes and high-value crops (Models G, H, K, L). These effects of farm size reflect that a further increase in farm size does not lead to expansion of cereal cultivation, since subsistence requirements are already largely met, but is used instead to expand the area of legumes and high-value crops.

Contrary to the simulation models (Section 5.4), the statistical analysis does not reveal any effect of household size and its squared value on the revenue of cereals and legumes (Models E, K), but household size does affect the cultivation of high-value crops, albeit with marginal decreasing effects. Clearly, abundant availability of household labour allows for a diversification into high-value crops, conditional on having a sufficiently large farm size to meet subsistence requirements. Contrary to expectations, increases in household labour availability do not have a similar effect on labour-intensive legume cultivation. However, use of hired labour does significantly increase average revenue from cereal and legume crops (Models I, J, K), but decreases the share of high-value crops (Model L). This suggests that hired labour is primarily used in production of the former crops, but dependence on hired labour leads farmers to downward adjust cultivation of high-value crops.

Higher livestock intensity positively affects average cereal revenue and the share of cereal revenue (Models E, I), but this effect disappears in the corrected models (Models F, J). On the other hand, increased livestock intensity does significantly increase average legume revenues, of which the residues are high quality sources of nutrition for livestock. Finally, there is weak evidence that use of manure benefits cereal cultivation, but not the other crop types. The effect of manure is weakly significant and positive in Model F, and positive, but not significant in Model J. Possibly the use of a stronger instrument could better identify the effect of manure. At the same time the effect of using manure is small, but significant. An increase in the use of manure with 1,000 kg/ha leads to an increase in the share of cereal revenues by 0.17%.

Fertilizer use increases the average revenue of all crop types (Models I-L), but appears to lower the share of cereals in total revenue (Model E), while this negative effect disappears when correcting for measurement errors in manure use (Model F). Furthermore, pesticide use is observed to increase the share of high-value crops in total revenue; crops which are indeed more prone to pests and diseases.

5.6 Discussion and conclusion

Crop-livestock integration (CLI) is viewed as one of the most important strategies to improve low and declining levels of soil fertility in the African savannas. However, farmers do not only keep livestock for maintaining soil fertility, by obtaining manure, which is subsequently used to redress soil fertility loss. Farmers also derive non-tangible benefits of keeping livestock, i.e., insurance, status, and financing benefits of keeping a herd. The relative importance of these factors may vary among farmers and locations, thus influencing efficient herd size and observed levels of CLI. Therefore, we use two complementary methods to analyse how such non-tangible benefits and CLI relate.

First, we use a farm household production model to jointly optimise crop and livestock production, accounting for different reasonable preferences for non-tangible benefits. The model is simulated for 120 farmers in the savannah region of Northern Nigeria. The results show that an increased importance of non-tangible benefits increases efficient herd size, frequently to levels below maintenance feeding. As a consequence of the larger herd however, the supply of organic matter also increases.

The simulation results further reveal an inverse U-shaped relation between labour per unit of cropland and herd size. It appears that crop-livestock integration is an efficient strategy at average levels of labour supply. At low levels, most labour is devoted to cultivating subsistence cereals. With increasing labour supply, legume cultivation becomes possible, thereby boosting the herd size with a supply of high-quality legume fodder. The results show that at higher levels of labour supply, legume cultivation decreases again in favour of the cultivation of high-value crops, mostly vegetables.

So far, most studies that explain differences in the degree of crop-livestock integration did so in relation to differential access to markets, mostly resulting from the theory laid out by McIntire *et al*. (1992). Our findings offer additional insights and show how farm-specific characteristics, such as labour availability, further lead to differences in CLI. Not surprisingly, we find that herd size and organic matter availability, i.e., rejected feed and manure, strongly correlate. Hence, increases in herd size due to increased importance of non-tangible benefits are also likely to lead to increased use of manure.

The household modelling approach would suggest that efficient herd size changes when a combination of both tangible and non-tangible benefits of keeping livestock are included in the objective function, although the magnitude of preferences for non-tangible benefits only has minor effects. In the approach followed the assumption is made that farmers maximise profits, whereby non-tangible benefits are monetized as suggested by Bosman *et al*. (1997). However, only assuming a purely economic objective is not likely to capture the multiple goals and objectives that play a role in the farmer decision-making process. These goals and objectives are better captured by using an approach similar to the one used in Chapter 3, further incorporating production attributes such as risk aversion in relation to non-tangible benefits of keeping livestock. However, this is outside the scope of the present study.

In the second part of this chapter we introduce a novel method to statistically estimate the magnitude of non-tangible benefits from herd size. We apply this method and analyse how household characteristics influence variation in this variable, In addition we compare how household characteristics influence use of manure and crop selection. The main findings are summarized in Table 5.10.

First, an increase in household size, *ceteris paribus*, leads to an increased likelihood of cultivating high-value crops, leading to higher levels of income that need to be stored, possibly in addition to higher off-farm incomes. At the same, higher income leads to increased non-tangible benefits of keeping livestock as measured by the difference between simulated maintenance herd size and actual herd size. These larger differences could indeed result from higher income, i.e., financing benefits, as well as an increased demand for insurance in larger households. As a result of the increased herd size, total manure supply is likely to increase and, combined with higher availability of household labour, indeed results in increased application of manure.

But, as shown in Table 5.10, the existence of such a pattern is conditional on farm size, which should be large enough to allow such diversification, after subsistence requirements are met. Thus, these results suggest the existence of two different groups of farmers. On the one hand, there exist a group of farmers with larger farms and higher labour supply that successfully diversify into market crops and maintain a larger herd to mitigate risks, and apply organic matter in larger amounts. On the other hand, there exists a group of farmers with small farms and insufficient labour supply, that are not able to diversify into market crops, have a too small herd to mitigate risks, and consequently only supply small quantities of manure.

Table 5.10: Observed effects relating to crop-livestock integration

Leads to: *A ceteris paribus increase in:*	*Cereals*	*Legumes*	*High value crops*	*Non-tangible benefits*	*Manure use*
Household Size	-	-	Increases share in total revenue and average revenue	Increases likelihood of excess herd size	Increases total use
Farm Size	-	Increases likelihood of cultivation	Increases likelihood of cultivation	Decreases likelihood of excess herd size	Decreases average use
Livestock intensity	-	Increases average revenue	-	n.a.	n.a.
Manure use	Increases share in total revenue	-	-	n.a.	n.a.

The table provides a summary of the main effects of household characteristics on indicators of crop-livestock integration and crop selection as observed in Tables 5.7 and 5.8.

While the interpretation of these findings is intuitively clear, a weakness in the approach followed remains. The data do not have information on additional purchases of feed resources, which might further explain the observed differences between simulated and observed herd size. However, given the bulkiness of fodder and lack of transport means, large sales and purchases of fodder outside a village are unlikely. Hence, if farmers do purchase additional feed, they are likely to do so from their neighbours. An important policy question then occurs as to which types of farmers sell, and which ones buy. This remains subject for further research.

The observed patterns of total livestock ownership, manure use and crop selection have some important implications. First, the results suggest that only ownership of small ruminants correlates with use of manure. On the other hand, total livestock ownership does influence the demand for legume fodder. These findings, in combination with the observed differences in ownership of livestock types, may suggest that farmers are heterogeneous in their preferences for keeping livestock. In fact, it may be useful to classify farmers on their livestock portfolio initially, and secondly carry out an empirical analysis to identify whether the production responses differ for farmers for which livestock plays a different role.

Furthermore, we identify a significant and negative correlation between use of manure and the distance to the nearest market. At the same time, the distance to market does not affect crop selection. Hence, this correlation suggests that manure use is higher in locations close to markets, which is contrary to the findings from the simulation model deployed by Abdoulaye and Lowenberg-DeBoer (2000) as well as in the model of McIntire *et al*. (1992). Both studies suggest manure use is likely to decrease if markets develop and supply of inorganic fertilizer becomes more constant and affordable. The latter aspect of market development may however not hold for all locations in this study, including the ones close to markets.

Our results suggest that non-tangible benefits of keeping livestock are highest at farms where labour supply per unit of farmland is highest. These same farms are most likely to cultivate high-value crops, and the higher non-tangible benefits likely result directly from financing and wealth storage benefits of livestock in the absence of formal financial institutions. The larger herd in itself induces a larger supply of on-farm manure.

Marenya and Barrett (2007) observed that inorganic and organic inputs are used complimentary and, in locations well integrated into markets, the use of both increases. This finding may also result from non-tangible benefits of keeping livestock, if the cultivation and the subsequent marketing of high-value crops are only feasible in locations close to market outlets. Then the revenues of such crops may be stored in livestock, and manure supply increases. Since markets are usually found close to major markets, the increased use of manure can also be confounded with increased use of organic urban waste. In one of the locations in our study such urban waste is likely to play an important role.

An important implication resulting from this line of reasoning is that the development and introduction of formal financial markets in rural areas may have a negative effect on the use of organic fertilizer. This should be addressed in additional research. In particular, the approach to quantify non-tangible benefits in this chapter could be used to compare rural locations that differ in access to formal financial institutions, to analyse whether such institutions lead to significant differences in non-tangible benefits. Furthermore, differences in access to savings accounts and insurance policies may well identify two of the separate components, financing and insurance benefits, which make up non-tangible benefits of keeping livestock.

Chapter 6

Discussion and conclusions

6.1 Heterogeneity in African agriculture

Growth in African agriculture greatly lags behind population growth. For example, average annual growth in agricultural production in Nigeria was 1.7% since the 1990s, while population growth stood at 2.6% (World Bank, 2008). As a result, most African countries, including Nigeria, turned from being surplus producers at independence to food importers today (FAOSTAT, 2009). Moreover, despite the success of green revolution technologies in Asia, adoption of such practices in Africa has been low. This is in part attributed to the large diversity of Africa, more specifically factors such as heterogeneity in soil fertility and other biophysical conditions, as well as in farm livelihood strategies, reflecting adverse policies. Furthermore, the low degree of infrastructure in Africa, as compared to many Asian countries, is frequently assumed to constrain growth (World Bank, 2008, Ch.2).

To increase low agricultural productivity and enhance the low quality of the soil resource base, implementation of a combination of site-specific technologies, policies and improved institutions is required (e.g., Ruben *et al*., 2001; Ehui and Pender, 2005). By consequence, agricultural research has moved towards creating a better understanding of the different types of heterogeneity observed, their drivers, and how they affects, e.g., the quality of the soil fertility resources in terms of their fertility status. Such research attempts to quantify heterogeneity, as well as to identify trade-offs, e.g., between production attributes such as profits and sustainability. With such information researchers can better assess the *ex ante* impact of new technologies and policies on production and soil resource use.

This study makes a contribution to quantification and better understanding of three specific types of household heterogeneity. More specifically, the first aim is to unravel the relationships between heterogeneity in goals and objectives on one hand and production decisions and nutrient budgets on the other hand. This research aim is addressed in both Chapters 2 and 3. The second aim is to relate heterogeneity in soil resources to productivity and efficiency, which is addressed in Chapter 4. The third aim is to relate heterogeneity in non-tangible benefits of keeping livestock to production decisions. This issue is investigated in Chapter 5.

The main finding in Chapter 2 is that heterogeneity in farmers' goals and objectives does significantly explain differences in agricultural productivity, although the bias incurred by ignoring heterogeneity is not likely to be very large. Next to well-described goals such as risk aversion, some new goals, such as a desire for self-sufficiency, are identified that affect production decisions.

Subsequently, Chapter 3 identifies the effect of heterogeneity on nutrient budgets, combining a bio-economic household simulation model and multi-attribute utility theory. Differences in goals and objectives appear to lead to considerable differences in soil nutrient budgets. Very few studies that apply such simulation models include heterogeneity in farmers' goals and objectives, which could lead to false conclusions and biased policy recommendations.

Chapter 4 concludes that ignoring within-farm heterogeneity in soil fertility can lead to erroneous conclusions on farm efficiency levels and biased policy recommendations that fail to address true determinants of inefficiencies, such as labour constraints.

In Chapter 5, the relative importance of non-tangible benefits of keeping livestock is investigated. As a first step, non-tangible benefits are included in a farm household simulation model. The results from this new approach suggest that the impact of non-tangible benefits is modest, though their relative importance is dependent on the specification of the criterion function in the simulation model. Second, a novel method is then used to empirically determine the magnitude of non-tangible benefits. These benefits are found to be larger for relatively larger households, that also frequently cultivate high-value crops. Hence, larger herds, and, by consequence, increased application of manure, could therefore be attributable to perceived higher non-tangible benefits of keeping livestock.

These findings have a number of implications and further questions. In the remainder of this chapter, three important issues are discussed. First, as shown in Chapters 2 and 3, considerable heterogeneity in farmers' objectives and goals is identified, some of which affect production decisions. In Section 6.2 an overview of the major findings of this study is given and the implications for further research are discussed. Second, a farm household modelling approach is used in Chapters 3 and 5. Given the need to better incorporate behavioural heterogeneity in such models, we discuss in Section 6.3 the future role of such simulation models, focusing on how to improve their accuracy. Finally, sustainable use of soil resources and its promotion has been a topic in all chapters in this study. Based on our major research findings, an overview is given in

Section 6.4 of how these can be used to enhance the sustainability of the use of soil resources in Sub-Saharan Africa. At the same time, remaining knowledge gaps are identified.

6.2 Understanding heterogeneous behaviour

As shown in Chapters 2 and 3, rural smallholder farmers in northern Nigeria differ considerably in their goals and objectives. That said, the results underline the importance of risk aversion, which is not unexpected given the ample attention risk has received in literature. In Chapter 3, risk aversion is operationalised by calculating the variance-covariance matrix of crop yields and analysing how actual farmers' crop choice relates to the best and worst outcomes of possible variance levels. In Chapter 2, a different approach is deployed, in which risk aversion is measured through a latent variable. This variable is identified with a factor analysis, which is applied to several Likert-type questions and a pair-wise goal ranking. Although different methods are used, both identified risk variables are found to significantly affect production. In Chapter 3, risk aversion leads to lower and/or negative nutrient budgets, while in Chapter 2, increases in risk aversion explain lower levels of profit efficiency and higher levels of food efficiency.

At the same time, the significance of variables measuring profit maximization, the most common assumption on behaviour in economic studies, appears to be modest at most. One latent variable is identified through the approach followed in Chapter 2 that relates to profit maximization, but this variable does not further explain differences in profit efficiency levels. A small group of farmers for whom profit maximization is an important objective are identified in Chapter 3.

Yet, it becomes clear that risk aversion is not the only attribute that influences production. In fact, the main reason for following the extensive approach in Chapter 2, combining a pair-wise goal ranking and additional questions, is to map the full diversity in goals and strategies. This approach also led to the identification of some not previously identified variables that affect production decisions. 'Striving to be a successful farmer in the future' and a strong orientation towards subsistence production, both influence production and efficiency levels. No other studies have identified these variables before.

Little of the variation in both these latent variables is explained by household characteristics. However, village dummies do explain significant differences in these variables, suggesting that social norms and other local conditions to some degree influence farmers' objectives. At the same time, considerable variation in these variables remains unexplained, suggesting these goals and objectives are to a large degree intrinsic to farmers, and not strongly dependent on characteristics like age and education level.

Finally, it is likely that environmental concerns of farmers, more specifically those related to maintaining soil fertility levels, partially explain production decisions at smallholder level in Africa, similar to the way they influence farmers in developed countries. However, the methodology aimed at identifying preferences or goals related to environmental concerns did not provide conclusive results. In Chapter 2, maintaining soil resource quality is included in the pair-wise goal ranking and is addressed in a number of questions as well. However, these measures do not appear to relate to the same latent variable, but the questions do correlate with technical efficiency levels, whereby a lower expressed ability or preference to maintain soil fertility levels leads to lower technical efficiency.

The approach followed in Chapter 3 does identify sustainability with regard to use of soil resources as an important attribute for a relatively large group of farmers. However, the resulting farm plans appear strongly similar to profit-efficient farm plans. Hence, it is not directly clear whether these weights solely measure preferences for use of soil resources, or a combination of multiple attributes.

The approaches followed in Chapters 2 and 3, although applied in several other instances, are different from frequently used experimental methods to measure preferences. Cardenas and Carpenter (2008), for example, present a synthesis of economic experiments with farmers in developing countries, focusing, amongst other things, on measuring risk aversion, altruism and/or time preferences.

The motivation for the non-experimental approach followed in Chapter 2 is to investigate which preferences or latent variables play a role in farm production decisions. This is done because there is no *a priori* reason to assume that such decisions only depend on, e.g., risk aversion. The significant effect of variables other than risk aversion and profit maximization confirms the relevance of this line of thought. Additional research should therefore aim at replicating these findings and methods need to be identified to more accurately measure these latent variables with more accuracy need to be identified. Potentially, this can be accomplished by using experimental field research methods.

In the approach followed in Chapter 2, farmers were not provided with any prospective payments when making their choices. The choices made in the pair-wise goal ranking and the answers given to the questions, were therefore in no respect motivated by a potential pay-off, but solely represented individual preferences.

However, the preferences displayed could also have been driven by differences in perceptions, of for example risk or the severity of soil fertility depletion. This in fact, is the main motivation in many studies for making use of a controlled field experiment, for example, to elicit risk preferences. Then, by presenting a game with a certain expected pay-off and a known distribution of outcomes, the perceptions of the associated risk are similar to all participants. The choices that the participants make are consequently only attributable to individual preferences and not to differences in perception.

Currently, experimental methods are still being refined to accurately measure preferences, for example risk preferences. A common approach to measure risk is derived from the expected utility theory, while at the same time much research findings show that the expected utility theory does not always hold (e.g., Thaler, 1999). Hence, research has set to measure risk as derived from cumulative prospect theory, making it a two-dimensional measure. Recently, Qiu and Steiger (2009) show that risk aversion measures of the components in both dimensions tend to be unrelated.

Further research should establish the best ways to measure variables such as risk preferences. At the same time advances in experimental field methods could be used to measure the other latent variables that are identified in the current research. Such measures can subsequently be used to analyse more accurately how these latent variables influence agricultural production decisions.

Clearly, the findings in this study suggest that a number of farmer production attributes, in addition to the well described attribute of risk aversion, influence agricultural production decisions and nutrient budgets. Furthermore, while the effects of different goals and objectives on productivity appear small, the effect on nutrient budgets was relatively large. Moreover, differences in farmers' goals and objectives may also explain other observed differences among smallholder farmers such as, e.g., (dis-)adoption of agricultural innovations as well as decisions with regard to off-farm employment.

6.3 Advancing simulation tools and methods

In Chapters 3 and 5, a simulation model based on mathematical programming methods is used. The results in Chapter 3 demonstrate that such models are sensitive to the specification of the criterion function. Hence, in order to obtain accurate and representative results from the application of a farm household model, the farmers included should not only be stratified according to endowments, but also with regard to goals and objectives. The methodology presented in Chapter 3 could serve as a basis, but further research needs to improve this method, such that the results can be given a level of statistical significance.

A promising way to obtain weights that more accurately reflect farmers' preferences would be to incorporate bootstrap methods in the methodology used in Chapter 3. This would be similar to methods used in e.g., Data Envelopment Analysis (e.g., Simar and Wilson, 1998). Such a modification would open up possibilities for a more detailed second-stage econometric analysis beyond the simple correlation analysis presented in Chapter 3. The accuracy of such an analysis, however, remains conditional on three important aspects. First, all production attributes that are relevant should be included in the analysis and be mutually utility-independent. As is clear from the discussion in Chapter 3, such an assumption may not always hold, while at the same time the condition of utility-independence is difficult to test in practice.

Second, and especially of concern in dynamic applications, there is little certainty that assumptions in a static framework remain valid over time. In fact, farmers' production attributes or preferences are likely to shift over time, as a result of which the criterion function or other components of the optimisation model could change. As yet, little is known about shifts in preferences. Moreover, since we use a static model in both Chapters 3 and 5, this point is not discussed in further detail.

Third, a representative analysis requires that the (bio-economic) farm household model itself be calibrated correctly. More specifically, the parameters are likely to be prone to measurement errors. The consequences of such inaccuracies, for which several options for improvement exist, are discussed in more detail below.

In agricultural economics, linear programming methods have been applied widely in the 1970s and 1980s, but lost ground in recent years, mainly because techniques from econometrics are better equipped to deal with the inherent stochastic nature of real-world problems. More specifically, a drawback of linear programming methods is that standard errors and confidence intervals of simulation outcomes are usually not computed. As a result, it becomes difficult to draw general conclusions. On the other hand, a main advantage of mathematical programming approaches is their applicability in research problems where identification of relationships with conventional econometrics techniques is intractable, or highly biased due to endogenous relationships among variables. For example, regression techniques would have been unable to determine the weights in the multi-attribute utility approach in Chapter 3.

At the same time, however, a detailed study estimating many parameters in detail, incurs great cost to a researcher. For example, the regression results from Chapter 4 suggest that within-farm differences in soil fertility lead to considerable differences in crop production levels. In the simulation models used in Chapters 3 and 5 no such within-farm differences were accounted for. The number of farmers included in the analysis would render accounting for detailed soil fertility differences, and their specific effects on crop production, impossible. The high cost involved in doing so would limit the analysis to a small number of farms only. By consequence, there would be no guarantee that these remaining farms would be representative in some way, given the considerable heterogeneity in goals, objectives and endowments. This is undesirable as the value of simulation models lies partially in their capability for establishing general results.

Next to the high-cost motive, a further argument against accounting for such farm differences, and/or other variables in disaggregated detail, would be the inevitability of measurement errors. Many applications of bio-economic models do not address measurement errors in data used, apart from yield uncertainty (e.g., Chapter 3 in this study; Tauer, 1983; Barbier, 1998). However, not only parameters related to yields are uncertain.

Many parameters in a farm household model are based on field surveys, sometimes complemented with expert knowledge, such as the labour requirements introduced in the various farming systems in Chapter 3. Many of these values are thus, at best, a rough estimate of their true values. Titonell (2008) equally stresses this concern, especially since labour requirements, prone to measurement errors, drive the solution, i.e. are binding constraints. This is observed in Chapter 3 as well, and these errors may therefore obscure insight in the model or system.

With the estimation of each additional disaggregated parameter in a simulation model, measurement errors affect the simulation results to some degree. More parameters are thus adding more uncertainty to the simulation results. In the end these measurement errors could be larger than the aggregation error if a higher level of analysis, i.e., assuming homogenous farm land quality, had been chosen.

Notwithstanding its declining use in empirical economics research, linear and non-linear programming methods are widely used for many purposes in modern-day society. Many of these applications take explicit account of stochastic properties of and/or measurement errors in parameters by using a number of techniques from operations research. Surprisingly, this methodological development has largely bypassed farming systems research.

A common approach is to apply calibration checks on the developed household model. This usually consists of a comparison of simulated with observed production decisions, assuming that a large similarity suggests that the model accurately reflects the true underlying farmer decision-making process. However, given the large number of parameters included in a model, all of which are subject to measurement errors and may drive the optimal solution in different directions, there is no guarantee that this method provides conclusive proof of model validation.

Furthermore, such a validation approach can only be successfully applied if full information on the criterion function, i.e. farmers' goals and objectives, are known, which is not commonly the case. In fact, the approach followed in Chapter 3 exploits the difference between actual and simulated cropping patterns, whereby the difference is hypothesized to relate to differences in farmers' goals and objectives.

Alternatively, researchers frequently apply sensitivity analysis to some key variables. This, however, is most often applied to the so-called right-hand side variables, i.e., the endowments, but not typically to variables in the production matrix, such as labour requirements, as that would be too time-consuming.

Hence, the impact of measurement errors in such parameters on model outcomes is often ignored, since the researcher does not have a reasonable alternative. However, alternative approaches to address this problem have been proposed, some of which may be easily applicable in (bio-) economic farm household models.

First, a number of stochastic programming approaches have been applied. Recourse models, for example, are suitable to model adaptive efficient farm behaviour, conditional on stochastic weather events and uncertain yield outcomes. Such a model has been implemented at farm-level in Burkina Faso (Maatman *et al.*, 2002). The model outcomes show how farmers efficiently shift labour between crops, based on realised weather outcomes, due to changes in marginal productivities.

In addition, the use of probabilistic programming methods has been advocated. Based on identification of a parameter that is susceptible to some stochastic event, some constraints are incorporated as chance constraints. The model is subsequently set-up such that these constraints hold for most outcomes of this stochastic event, commonly in 95% of the cases. Application of such approaches is, however, marred by some difficulties. First, the actual distribution of the stochastic event has to be specified in detail, which is not always feasible. Secondly, and more importantly, in many instances the resulting solution set of the associated mathematical programming problem is no longer convex (e.g., Ben-Tal *et al.*, 2006), limiting identification of an optimal solution.

An alternative development is so-called robust optimisation. In this method, it is implicitly assumed that some parameters, such as labour demand in the case of a farm household model, are uncertain. Instead of setting such a parameter to a single best estimate, an interval is pre-specified, containing all likely values of this parameter. For example, instead of setting monthly labour requirements in a cropping system to 600 man-hours per hectare, it may be more reasonable to assume this requirement to fall between 550 and 650 hours per hectare. This may also reflect the fact that a farmer adapts his strategy to weather outcomes, leading to higher or lower labour use, conditional on a certain target output target level.

The optimisation approach subsequently searches for the best solution that holds for all labour parameters in this interval. The technicalities of the method, its main motivations and applications are described in more detail by Ben-Tal and

Nemirovski (1998; 1999; 2008). Contrary to chance-constrained optimisation, convexity is maintained in robust optimisation approaches, making it computationally suitable for the introduction in bio-economic farm household models, leading to more reliable modelling outcomes.

Hence, the research in this study has illustrated that it is crucial to incorporate an accurate representation of farmers' objectives in a bio-economic simulation model. The discussion above indicates that the reliability of such simulation models can further benefit from a correction for data uncertainties. These improvements are necessary to analyse how soil fertility replenishment can be stimulated at smallholder level in Africa. Based on the findings in this study we now turn to a number of potential avenues for enhancing sustainable use of soil resources.

6.4 Promoting sustainable use of soil resources

The results from the application of the bio-economic simulation model in Chapter 3 show that nutrient budgets are, not surprisingly, highest and mostly positive for farmers with a strong revealed preference for the sustainability attribute. Preference for many of the other attributes, including risk aversion and some instances of maximisation of gross margins, soil nutrient budgets are negative. As discussed in Section 6.2, it is not directly clear whether these farmers choose sustainable cropping patterns solely for reasons of sustainability, or that other attributes play a role. What does become clear is that sustainable cropping patterns include the cultivation of high-value crops, with higher nutrient input levels. Furthermore, farmers characterized by high degrees of risk aversion will not choose such cropping plans, but choose cropping plans that are less sensitive to risk. Less risk-sensitive cropping plans are dominated by cereal crops, characterized by lower input levels and higher levels of nutrients removed in crop products. This explains the lower or negative nutrient budgets, particularly for phosphorus and potassium.

In the simulation model used in Chapter 3, only macronutrients were considered. Recent soil research suggests that micronutrients are increasingly becoming depleted, especially in the wake of higher use of inorganic fertilizer. The increased use of manure can play an important role in recycling such nutrients.

At the same time, the results of this study clearly illustrate the consequences for production to farmers that diversity less in profitable high-value crops. The efficiency analysis in Chapter 4 illustrates the effect of narrower rotation among types of crops, and a stronger dominance of cereals in the cropping pattern, on production levels. In most locations, narrower rotation result in decreases in maize yields. This decrease likely results from both, lower soil fertility levels and increased pest and disease pressure. While rotation does not appear to affect sorghum production, all regression results in Chapter 4 highlight the importance of differences in soil fertility on production and efficiency levels.

Chapter 5 further illustrates the relationships between farm types, crop types cultivated, livestock ownership and use of manure. The results from the farm household model show how optimal herd size depends on the availability of fodder from legume and cereal residues. The supply of fodder in itself depends on availability of labour and land, the most important endowments of smallholders. Furthermore, the simulation results suggest that at the highest levels of labour availability per unit of farmland, farmers increase the cultivation of high-value crops, resulting in reduced supply of fodder crops and herd size.

Yet, the subsequent regression analysis in this chapter does not confirm these findings. While the analysis shows that at the highest levels of labour availability, cultivation of high-value crops is most extensive, it also reveals that such farmers maintain herd sizes that are ‘too large’, given actual fodder availability. Furthermore, the regression analysis in Chapter 5 shows that the cultivation of high-value crops is conditional on the availability of a sufficiently large farm, while similarly in Chapter 3 it is shown that levels of risk aversion decrease (and the cultivation of high-value crops increases) with increasing farm size. Given the larger herd size such farmers keep, manure use is also higher, further facilitated by higher labour availability.

The regression results in Chapter 5 suggest manure is only used on cereals, while the analysis in Chapter 4 suggests this mostly benefits sorghum production. Marenya and Barrett (2007) also suggest manure to be used on crops selectively, mostly in cereal subsistence production. Similarly, many of the integrated crop-livestock systems stimulate the use of manure on cereal crops, since legumes fix nitrogen naturally, and may only need some additional phosphorus. Hence, the total mix of soil nutrients in manure will benefit cereals the most.

Again, and similar to those of Marenya and Barrett (2007), our results suggest that use of both inorganic and organic fertilizer increases jointly, but only in the relatively wealthy households, i.e., those with sufficient household and farm sizes. The explanation offered is that herd size increases at these farms as a result of increased non-tangible benefits, in particular financing benefits. An important implication of this hypothesis is that manure use is likely to decrease when formal financial institutions develop. Very little is yet known on the relationship between (in)formal financial arrangements and crop-livestock integration. Given the important role of organic fertilizers in combating soil fertility decline, also with regard to recycling micronutrients, more research on this subject is urgently needed.

The methodology developed in Chapter 5 to identify non-tangible benefits of keeping livestock can thereby be used further. This method can be used to calculate such benefits in households and/or villages that differ in access to financial services. Similarly to the approach followed in the second part of Chapter 5, an econometric regression can identify the effect of access to formal financial services on herd size.

More worryingly, however, is the suggestion of Rufino (2008) that nutrient losses in integrated crop-livestock systems are highest in the poorest households. Hence, even while the quantities of nutrients recycled are lower, the losses are higher too. At the same time, this can be a result of less available labour to transport manure. Unfortunately, the prospect for reducing labour costs of using manure seems limited, given its bulkiness and the low levels of infrastructure and mechanisation. Again, these results suggest the need for specific policies to assist the poorest groups of farmers, who may, at least from the point of soil fertility resources, be caught in a poverty trap.

Clearly, designing policies that can engage groups of risk-averse farmers in the cultivation of high-value crops, without the full exposure to risk may thereby also lead to more sustainable use of soil resources. While policies aimed at facilitating input use can be designed and implemented relatively easy, it is more difficult to reduce the actual risk exposure to the poorest and most risk-averse groups of farmers. The potential for risk-sharing arrangements among farmers in one location is likely to be low, because the risk of crop failure in a particular location is covariant (as it largely depends on external factors such as weather conditions and the occurrence of pests and diseases).

The exact potential for cooperation in sharing risks and their impact on soil nutrient budgets could be further analysed by combining a farm household simulation model with concepts from cooperative game theory. Cooperative agreements among farmers continue to play an important role between farmers, even in areas well-integrated into markets. In Burkina Faso, many farmers are engaged in sharecropping arrangements (Bernard *et al.*, 2008a, 2008b). Furthermore, in other instances, farmers engage in cooperative agreements to manage natural resources in a sustainable way (e.g., Boone *et al.*, 2005). The potential role of farmer (cooperative) organisations in managing natural resources is acknowledged by the World Bank (2008).

Yet, empirical studies suggest that only similar (or similarly endowed) farmers cooperate, which is also called the middling effect (Bardhan, 2000), because the poorest farmers have little to contribute, while the richest do not need a cooperative. Very few studies, however, quantify the differences in returns to participants in a cooperative. In a recent study (Gerichhausen *et al.*, 2009), we introduce a framework to analyse the costs and benefits of cooperation. The framework is based on a farm household model, while division rules from cooperative game theory are applied to partition additional revenues generated by entering a cooperative agreement. In such a way, agreements can be identified in which all participants have an incentive to cooperate, i.e., their revenues are higher in a cooperation compared to a situation in which they farm alone.

Application of this framework by the authors, using the farm household model developed in the current study, shows that in the absence of transaction costs all farmers, poor and rich, cooperate in a hypothetical sharecropping arrangement. On the other hand, introduction of transaction costs, such as costs of meeting, travel and moral hazard, replicates the middling effect. Since the framework is based on separate farm households, it can directly be extended with soil nutrient budgets and multiple attributes, including risk aversion. This framework can then be further used to guide policy design that enhances the sustainable use of soil resources, particularly for the least-endowed groups of farmers.

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Appendix A

Appendix to Chapter 2. Questionnaire and DEA-models.

A.1 Questions included in survey eliciting farmer goals and preferences

Table A.1: Questions included in the survey.

#	Question
Q1	It is our duty to produce enough from the farm for our own family needs
Q2	If I could earn more money on the market, I would sell all my produce
Q3	It is better to consume your produce than to sell it
Q4	I only sell crops when I need to buy other amenities (food, clothes, medicare, school etc.). Otherwise I store my harvest.
Q5	In the future I would like to grow more crops for sale
Q6	I want to have a bigger farm to expand my farm business
Q7	I prefer Sorghum over Maize because the yields vary less
Q8	Growing a lot of different crops reduces the risk of farming
Q9	The best farmers are the ones that take more risks
Q10	Since the prices of commodities fluctuate a lot, I prefer to produce strictly for my own needs
Q11	I find manure application and other measures of soil maintenance too cumbersome
Q12	In order to make money and/or produce enough food for my family I sometimes have to do things which are not good to the soil
Q13	To secure good production in the future, I invest in my soils every year
Q14	I cannot influence the yields/production through soil management
Q15	Farming is too arduous for me
Q16	Other jobs and activities give me more satisfaction than farming
Q17	I encourage my children to find another profession in the future

A.2 Definitions of variables and parameters used in Data Envelopment Analysis Models

Table A.2: Definition of sets used in Data Envelopment Analysis models

Set	*Description*	*Contents*
P	Peers	
$F=P$	Firms	
O	Outputs	Cereals; Legumes; High value crops; Rice; Sugarcane
I	Variable inputs	Fertilizer; Manure; Pesticide; Hired labor
K	Fixed inputs	Household labor; Farm size; Fadama size

Table A.3: Definition of parameters used in Data Envelopment Analysis models

Parameter	*Description*
$z_{f,k}$	Use of fixed inputs k by farmer f under consideration
$z_{p,k}$	Use of fixed inputs k by potential peer farmer p
$x_{f,i}$	Use of variable inputs i by farmer f under consideration
$x_{p,i}$	Use of variable inputs i by potential peer farmer p
$y_{f,o}$	Level of output o of farmer f under consideration
$y_{p,o}$	Level of output o of potential peer farmer p
π_f	Actual profit level of farmer f under consideration
ψ_f	Actual food production level of farmer f under consideration

Table A.4: Definition of decision variables used in Data Envelopment Analysis models

Variable	*Description*
$X^*_{f,i}$	Feasible alternative input level for farmer f under consideration
$Y^*_{f,o}$	Feasible alternative output level for farmer f under consideration
Λ_p	Weight given to peer p
Π_f	Feasible alternative profit level for farmer f under consideration
Ψ_f	Feasible alternative food production level for farmer f under consideration
PE_f	Profit efficiency level of farmer f
PAE_f	Profit allocative efficiency level of farmer f
FE_f	Food efficiency level of farmer f
FAE_f	Food allocative efficiency level of farmer f
α_f	Technical (input-oriented) efficiency level of farmer f
β_f	Technical (output-oriented) efficiency level of farmer f

A.3 Mathematical description of profit efficiency DEA-model

$$\text{Max } \Pi_f = \sum_{o \in O} Y^*_{f,o} * p_o - \sum_{i \in I} X^*_{f,i} * v_i - \sum_{k \in K} z_{f,k} * v_k \tag{A.1}$$

$$z_{f,k} \geq \sum_{p \in P} z_{p,k} * \Lambda_p \qquad \forall k = 1, \ldots, K \tag{A.2}$$

$$X^*_{f,i} \geq \sum_{p \in P} x_{p,i} * \Lambda_p \qquad \forall i = 1, \ldots, I \tag{A.3}$$

$$Y^*_{f,o} \leq \sum_{p \in P} y_{p,o} * \Lambda_p \qquad \forall o = 1, \ldots, O \tag{A.4}$$

$$\sum_{p \in P} \Lambda_p = 1 \tag{A.5}$$

$$PE_f = \pi_f / \Pi_f \tag{A.6}$$

This mathematical model, using the notation introduced in Tables A.2, A.3 and A.4, is solved for each farmer individually, whereby all farmers in the data set, including the farmer under consideration, act as potential peers. In this specification weights Λ_p are chosen such that the potential profit in (A.1), based on feasible input and output levels $X^*_{f,i}$ and $Y^*_{f,o}$, is highest. The weights determine a weighted combination of fixed inputs, variable inputs and outputs of peer farmers by (A.2), (A.3) and (A.4) respectively. Feasible input and output levels for farmer f, $X^*_{f,i}$ and $Y^*_{f,o}$, which in most cased differ from observed input and output levels $x_{f,i}$ and $y_{f,o}$, are constrained by the weighted combinations (A.2), (A.3) and (A.4). In the profit specification (A.1), the costs of observed fixed input levels are included without loss of generality, while (A.2) ensures that use of fixed inputs in the weighted combination of peers is not greater than observed levels of fixed input. The profit of the resulting combination of inputs and outputs is determined by (A.1) and compared with actual profit in (A.6) to determine the efficiency score. By construction the efficiency score has an upper bound of 1, which is achieved if no combination of farmers gives a profit higher than the actual profit of the farmer under consideration. Finally, the weights sum up to 1 as a result of (A.5).

Subsequently, for each farmer a measure of profit allocative efficiency (PAE_f) is determined by applying an additive decomposition (A.7) of total profit lost due to inefficiency (e.g., Ray, 2004, p.233). In this decomposition, Π_f is the efficient profit level determined in (A.1), π_f is the actual profit level of a farmer based on observed input and output levels, C_f is the actual cost based on observed input levels and α_f is an input-oriented measure of technical efficiency.

$$PAE_f = \frac{(\Pi_f - \pi_f)}{C_f} - [1 - \alpha_f] \qquad \text{(A.7)}$$

The measure α_f is obtained by solving the mathematical program defined by (A.8) – (A.12), again using the notation introduced in Tables A.2, A.3 and A.4. In the mathematical program the minimum feasible level of input use (or maximal reduction in inputs) while holding the levels of output constant (A.11), is determined through (A.9) and (A.10). Furthermore, (A.9) ensures that use of fixed inputs in the weighted combination of peers is not greater than observed levels of fixed input. Both input and output levels are conditional on a weighted combination of peers through the choice of Λ_p.

$$\text{Min } \alpha_f \qquad \text{(A.8)}$$

$$z_{f,k} \geq \sum_{p \in P} z_{p,k} * \Lambda_p \qquad \forall k = 1, \ldots, K \quad \text{(A.9)}$$

$$x_{f,i} * \alpha_f \geq \sum_{p \in P} x_{p,i} * \Lambda_p \qquad \forall i = 1, \ldots, I \quad \text{(A.10)}$$

$$y_{f,o} \leq \sum_{p \in P} y_{p,o} * \Lambda_p \qquad \forall o = 1, \ldots, O \quad \text{(A.11)}$$

$$\sum_{p \in P} \Lambda_p = 1 \qquad \text{(A.12)}$$

A.4 Mathematical description of food efficiency DEA-model

$$\text{Max } \Psi_f = \sum_{o \in O} Y^*_{f,o} * e_o \tag{A.13}$$

$$z_{f,k} \geq \sum_{p \in P} z_{p,k} * \Lambda_p \qquad \forall k = 1, \ldots, K \tag{A.14}$$

$$X^*_{f,i} \geq \sum_{p \in P} x_{p,i} * \Lambda_p \qquad \forall i = 1, \ldots, I \tag{A.15}$$

$$Y^*_{f,o} \leq \sum_{p \in P} y_{p,o} * \Lambda_p \qquad \forall o = 1, \ldots, O \tag{A.16}$$

$$\sum_{p \in P} \Lambda_p = 1 \tag{A.17}$$

$$FE_f = \psi_f / \Psi_f \tag{A.18}$$

This mathematical model, using the notation introduced in Tables A.2, A.3 and A.4, is solved for each farmer individually, whereby all farmers in the data set, including the farmer under consideration, act as potential peers. In this specification weights Λ_p are chosen such that the potential food production in (A.1), based on feasible output levels $Y^*_{f,o}$, is highest. The weights determine a weighted combination of fixed inputs, variable inputs and outputs of peer farmers by (A.14), (A.15) and (A.16) respectively. Feasible input and output levels for farmer f, $X^*_{f,i}$ and $Y^*_{f,o}$, which in most cased differ from observed input and output levels $x_{f,i}$ and $y_{f,o}$, are constrained by the weighted combinations (A.15) and (A.16). Furthermore, (A.14) ensures that use of fixed inputs in the weighted combination of peers is not greater than observed levels of fixed input. The food production of the resulting weighted combination are determined by (A.13) and compared with actual food production in (A.18) to determine the efficiency score. By construction the efficiency score has an upper bound of 1, which is achieved if no combination of farmers gives a food production higher than the actual food production of the farmer under consideration. Finally, the weights sum up to 1 as a result of (A.17).

Subsequently, food efficiency is decomposed into technical output-oriented efficiency, β_f, and food allocative efficiency, FAE_f, by applying (A.19).

$$FE_f = FAE_f * \frac{1}{\beta_f} \tag{A.19}$$

The measure β_f is obtained by solving the mathematical program defined by (A.20) – (A.24), again using the notation introduced in Tables A.2, A.3 and A.4. In this mathematical program the maximum feasible output level (or maximal increase in outputs) is determined by (A.20) and (A.23), while input levels are held constant by (A.21) and (A.22). Both input and output levels are conditional on a weighted combination of peers through the choice of Λ_p.

$$\text{Max } \beta_f \qquad \text{(A.20)}$$

$$z_{f,k} \geq \sum_{p \in P} z_{p,k} * \Lambda_p \qquad \forall k = 1, \ldots, K \quad \text{(A.21)}$$

$$x_{f,i} \geq \sum_{p \in P} x_{p,i} * \Lambda_p \qquad \forall i = 1, \ldots, I \quad \text{(A.22)}$$

$$y_{f,o} * \beta_f \leq \sum_{p \in P} y_{p,o} * \Lambda_p \qquad \forall o = 1, \ldots, O \quad \text{(A.23)}$$

$$\sum_{p \in P} \Lambda_p = 1 \qquad \text{(A.24)}$$

Appendix B

Appendix to Chapters 3 and 5. Mathematical description of bioeconomic farm household model.

B.1 Definitions of variables and parameters used in bioeconomic model

Table B.1: Definition of sets used in bioeconomic model

Set	*Description*	*Contents*
I	Inputs	NPK; Urea; SSP; Cypermethrin
K	Food requirements	Energy; Protein
L	Labour types	Manual labour only; Manual with Animal labour
M	Products	Maize; Cowpea; Groundnut; Soybean; Sorghum; Rice; Cocoyam; Tomatoes; Hot Pepper; Sugarcane; Sweet Potatoes; Irish Potatoes; Okra; Late Millet; Maize Fodder; Cowpea Fodder; Groundnut Fodder; Soybean Fodder; Sorghum Fodder; Millet Fodder
$PM \subseteq M$	Perishable products	Tomatoes; Hot Pepper
$NM \subseteq M$	Non-consumable products	Products that are not counted in household energy production: Sugarcane, Tomatoes, Hot Pepper; Maize Fodder; Cowpea Fodder; Groundnut Fodder; Soybean Fodder; Sorghum Fodder; Millet Fodder
$FM \subseteq M$	Fodder products	Maize Fodder; Cowpea Fodder; Groundnut Fodder; Soybean Fodder; Sorghum Fodder; Millet Fodder
N	Cropping Systems	Single cropping system are based on all crops *M*, whereby either high or low amounts of inputs can be applied. Furthermore, two commonly observed intercropping systems are included: Sorghum-Cowpea relay; Maize-Cowpea relay. Again, both intercropped systems can be cultivated with either high or low input use
$FN \subseteq N$	Cropping systems suitable for fadama fields	All cropping systems which include Sugarcane; Rice; Tomatoes; Hot Pepper
S	Soil nutrients	Nitrogen; Phosphorus; Potassium
T	Months	April; May; June; July; August; September; October; November; December; January; February; March
$TT \subseteq T$	Target production months	November; December; January; February; March

The table above provides the contents of each of the sets used in the bioeconomic model applied in Chapters 3 and 5.

Table B.2: Definition of objectives used in bioeconomic model

Objective	*Unit*	*Definition*
GMN	Naira	Attribute to maximize gross margins of products
SUS	Kg	Attribute to maximize nitrogen soil balance
VAR	Naira	Attribute to minimize variance or standard deviation of production plan
LAB	Hours	Attribute to minimize labor use

The above four objectives are further defined mathematically in Section B.2.12, equations (B.34) till (B.37). These four objectives are used to define four different simulation scenarios for each farmer in Chapter 3.

Table B.3: Definition of decision variables used in bioeconomic model

Variable	*Unit*	*Definition*
$AN_{r,f}$	#	Total number of goats being fed at feeding level *f* with ration *r*
BNF_s	kg	Quantity of nutrient *s* added due to Biological Nitrogen Fixation.
$BUY_{m,t}$	kg	Quantity bought of product *m* during period *t*.
CAP_t	Naira	Capital stock on hand at the start of period *t*.
$CNS_{m,t}$	kg	Total quantity consumed of product *m* during period *t*.
$CSO_{m,t}$	kg	Quantity consumed of product *m* during period *t* from own produce.
$CSP_{m,t}$	kg	Quantity consumed of product *m* during period *t* from market purchased products.
HAL_t	hrs	Total time of hired animal (bull) labour used in period *t*.
HWL_t	hrs	Total time of wage labour used in period *t*.
$IPA_{i,t}$	kg	Total amount of input *i* applied during period *t*.
ITP_t	Naira	Total amount of interest paid during period *t*.
$LAN_{n,l}$	ha	Surface cultivated with cropping system *n* with labour system *l*
LON_t	Naira	Amount of outstanding loan at the start of period *t*
NAF_s	kg	Quantity of nutrient *s* added through (in)organic fertilizer application
NLF_s	kg	Quantity of nutrient *s* removed in harvested fodder products
NLG_s	kg	Quantity of nutrient *s* lost through gaseous losses
NLH_s	kg	Quantity of nutrient *s* removed in harvested product
NLN_t	Naira	Amount of new loan taken during period *t*
NUT_s	kg	Balance of nutrient *s* after one year
OLR_t	hrs	Total time of labour devoted to off/non-farm activities during period *t*
$PRD_{m,t}$	kg	Quantity harvested of product *m* during period *t*
RLN_t	Naira	Amount of loans repaid during period *t*
$SEL_{m,t}$	kg	Quantity sold of product *m* during period *t*
$STO_{m,t}$	kg	Quantity of product *m* stored at the start of period *t* in the store with own produced products
$STP_{m,t}$	kg	Quantity of product m stored at the start of period *t* in the store with market purchased products
TLG	kg	Total annual gain in live weight of the herd size
TPD_m	kg	Quantity produced of product *m* in cropping season
VAR	Naira	Total Variance of chosen production plan
VAN	Naira	Total Variance of chosen production plan if negative
VAP	Naira	Total Variance of chosen production plan if positive

The table provides a formal definition of the decision variables included in the bioeconomic model used in Chapters 3 and 5. Their use in the model is formally introduced in Section B.2, where all equations and constraints are discussed.

Table B.4: Definition of farmer-specific parameters used in bioeconomic model

Parameter	*Unit*	*Definition*
ala_t	hrs	Animal (Bull) Labour available during period *t*
fds	ha	Total surface of fadama fields available to the farmer
frs	ha	Total surface of farmland available to the farmer
ini_t	Naira	Other household income in period *t*
lfr	hrs hrs^{-1}	Fraction of total available labour that can be used for off-non/ farm activities
mla_t	hrs	Family Labour available during period *t*
mep_t	Naira	Other household expenditures in period *t*
mln	Naira	Maximum amount of credit available to the farmer during the cropping season

The table provides a formal definition of all the farmer-specific parameters included in the bioeconomic model used in Chapters 3 and 5. Hence, these parameter define the farmers' resource vector. Their use in the model is formally introduced in Section B.2, where all equations and constraints are discussed. In addition, Table B.6 provides an overview of the data sources used to estimate these parameters.

Table B.5: Definition of common parameters used in bioeconomic model

Parameter	*Unit*	*Definition*
$alr_{n,t,l}$	hrs ha^{-1}	Animal labour required for the cultivation of cropping system n during period t with labour system l
awr_t	Naira hr^{-1}	Animal wage rate during period t
$cov_{n1,n2}$	Naira^2 hr^{-2}	Covariance of average income between cropping system $n1$ and cropping system $n2$ based on one hectare
dom_{rfm}	kg goat^{-1} year^{-1}	Annual requirement of product m of one goat when maintained at feeding level f and ration r
$fnc_{m,k}$	kg kg^{-1}	Quantity of nutrients of type k in product m
fnr_k	kg	Quantity of food requirements of type k required by the farming household per month
glc_s		Parameter used to calculate gaseous losses from fertilizer application
gli_s		Intercept used to calculate gaseous losses from nutrient application
$inp_{i,t}$	Naira kg^{-1}	Market price of input i during period t
int	Naira	Periodical interest rate on loans
$ipr_{i,n,t}$	kg ha^{-1}	Amount of input i required for cultivation of cropping system n during period t
lwg_f	kg goat^{-1} year^{-1}	Annual gain in live weight of a goat kept at feeding level f and ration r
mln	Naira	Maximum amount of credit available to the farmer during the cropping season
$mlr_{n,t,l}$	hrs ha^{-1}	Manual labour required for the cultivation of cropping system n during period t with labour system l
mwr_t	Naira hr^{-1}	Agricultural wage labour rate during period t
$opp_{m,t}$	Naira kg^{-1}	Market price of product m during period t for market purchases
$ops_{m,t}$	Naira kg^{-1}	Market price of product m during period t for market sales
$sfc_{s,i}$	kg kg^{-1}	Amount of soil nutrient s contained in input i
$sff_{s,m}$	kg kg^{-1}	Fraction of total uptake of soil nutrient s obtained through biological nitrogen fixation in cropping system i
$sfh_{s,m}$	kg ha^{-1}	Amount of soil nutrient s removed in harvest of cropping system i
snd_s	kg ha^{-1}	Average quantity of soil nutrient s deposited through wind and rain during one year
sne_s	kg ha^{-1}	Average quantity of nutrient s lost through wind and water erosion during one year
$yld_{n,m,t}$	kg ha^{-1}	Yield of product m from cropping system n during period t

The table provides a formal definition of all common parameters included in the bioeconomic model used in Chapters 3 and 5. These parameters do not vary between farmers. Their use in the model is formally introduced in Section B.2, where all equations and constraints are discussed. In addition, Table B.6 provides an overview of the data sources used to estimate these parameters.

Table B.6: Data sources of parameters used in bioeconomic model

Parameters	*Source*
awr_t, $alr_{n,t,l}$, ini_t, $mlr_{n,tl,l}$, mln, mep_t, $hmwr$	Estimated based on household production and consumption survey in 2005
ala_t, fds, frs, $ipr_{i,n,t}$, int, mla_t, $yld_{n,m,t}$	Estimated based on baseline survey in 2002
$ipp_{i,t}$, $ops_{m,t}$, $opp_{m,t}$	Estimated based on data obtained from various government agencies
snd_s, fnr_k, sne_s, $sfc_{s,i}$, $sff_{s,m}$, $sfc_{s,m}$, gli_s, glc_s, $fnc_{m,k}$	Estimated from various FAO sources (FAO, 2004a; 2004b, 2004c, 2006)
lfr	No detailed estimation possible. Various values of the parameter are used, with neither of these exceeding 0.25, based on local observations

The table provides an overview of the data sources used to the parameters introduced in Tables B.4 and B.5.

B.2 Mathematical description of profit efficiency DEA-model

This section provides a detailed overview of each of the equations and constraints of the bioeconomic model used in Chapters 3 and 5.

B.2.1 Financial balances and constraints

$$
\begin{aligned}
CAP_t &= CAP_{t-1} + \sum_{m=1}^{M} SEL_{m,t-1} * ops_{m,t-1} - \sum_{m=1}^{M} BUY_{m,t-1} * opp_{m,t-1} - \sum_{i=1}^{I} IPA_{i,t-1} * inp_{i,t-1} \\
&+ \left[OLR_{t-1} - HWL_{t-1} \right] * mwr_{t-1} - HAL_{t-1} * awr_{t-1} + ini_{t-1} - mep_{t-1} - RLN_{t-1} + NLN_{t-1} \\
&- ITP_{t-1} \qquad \text{(B.1)}
\end{aligned}
$$

Constraint (B.1) is a monthly capital balance, calculating the amount of money at hand in the farming household. Capital in a certain month depends on capital in the previous month, plus income from net sales of harvested product at the market, less expenditures on farming inputs, plus income from wage labour, less expenditures on wage labour, plus or less other sources of income and expenditures, plus or less changes in loans and less costs of maintaining loans.

$$
LON_t = LON_{t-1} + NLN_{t-1} - RLN_{t-1} \qquad \forall t = 1,\ldots,T \qquad \text{(B.2)}
$$

Equation (B.2) is a monthly balance, determining the total amount of loan outstanding, depending on loans in the previous month, repaid loans and new loans.

$$\sum_{t=1}^{T} NLN_t \leq mln \qquad \text{(B.3)}$$

Constraint (B.3) ensures that the total amount of loans taken during the planning period does not exceed the maximum amount possible.

$$\sum_{t=1}^{T} RLN_t = \sum_{t=1}^{T} NLN_t \qquad \text{(B.4)}$$

Equation (B.4) ensures that the total amount of loans taken during the planning period is repaid at the end of the planning period.

$$ITP_t = LON_t * int \qquad \forall t = 1, \ldots, T \qquad \text{(B.5)}$$

Equation (B.5) determines the required monthly interest payments.

B.2.2. Land use constraints

$$\sum_{n=1}^{N} \sum_{l=1}^{L} LAN_{n,l} \leq frs \qquad \text{(B.6)}$$

Constraint (B.6) ensures that the total size of chosen landuse does not exceed the total farm size of the farmer.

$$\sum_{fn=1}^{FN} \sum_{l=1}^{L} LAN_{fn,l} \leq fds \qquad \text{(B.7)}$$

Constraint (B.7) ensures that the total size of chosen fadama landuse does not exceed the total fadama size of the farmer.

B.2.3 Labour use constraints

$$\sum_{n=1}^{N} \sum_{l=1}^{L} LAN_{n,l} * mlr_{n,t,l} \leq mla_t + HWL_t - OLR_t \qquad \forall t = 1, \ldots, T \qquad \text{(B.8)}$$

Constraint (B.8) ensures that the monthly labour requirements, induced by the chosen landuse-options, are met by family labour, less possible other wage labour activities, plus hired labour.

$$\sum_{n=1}^{N}\sum_{l=1}^{L} LAN_{n,l} * alr_{n,t,l} \leq ala_t \qquad \forall t = 1,\ldots,T \tag{B.9}$$

Constraint (B.9) is identical to (B.8), though focuses on animal (bull) labour.

$$OLR_t \leq mla_t * lfr \qquad \forall t = 1,\ldots,T \tag{B.10}$$

Constraint (B.10) ensures that labour spent on other non- or off-farm activities (such as wage labour) are restricted so a pre-set maximum.

B.2.4 Production balances

$$PRD_{m,t} = \sum_{n=1}^{N}\sum_{l=1}^{L} LAN_{n,l} * yld_{n,m,t} \qquad \forall m = 1,\ldots,M \quad \forall t = 1,\ldots,T \tag{B.11}$$

Equation (B.11) relates production of products to chosen landuse-options through estimated yields.

$$TPD_m = \sum_{t=1}^{T} PRD_{m,t} \qquad \forall m = 1,\ldots,M \tag{B.12}$$

Equation (B.12) sums up production throughout the year to total production.

B.2.5 Input use balance

$$IPA_{i,t} = \sum_{n=1}^{N}\sum_{l=1}^{L} ipr_{i,n,t} * LAN_{n,l} \qquad \forall i = 1,\ldots,I \quad \forall t = 1,\ldots,T \tag{B.13}$$

Equation (B.13) determines the total amount of inputs required as a result of the chosen landuse-options.

B.2.6 Storage balances

$$STO_{m,t} = STO_{m,t-1} + PRD_{m,t-1} - CSO_{m,t-1} - SEL_{m,t-1} \quad \forall m = 1,\ldots,M \quad \forall t = 1,\ldots,T \tag{B.14}$$

Equation (B.14) is a storage balance for products from the farmer's fields. It depends on the produce in store in the previous period, consumption and sales.

$$STP_{m,t} = STP_{m,t-1} - CSP_{m,t-1} + BUY_{m,t-1} \quad \forall m = 1,\ldots,M \quad \forall t = 1,\ldots,T \tag{B.15}$$

Equation (B.15) is a storage balance for products purchased at the market place. It depends on the produce in the store in the previous period, consumption and purchases. The division between $STO_{m,t}$ and $FST_{m,t}$ is an artificial one, to prevent the model outcome to include profits from hedging on market prices.

$$\sum_{pm=1}^{PM} STO_{pm,t} = 0 \quad \forall t = 1,\ldots,T \tag{B.16}$$

Equation (B.16) ensures that perishable products are not stored.

B.2.7 Consumption balances

$$CNS_{m,t} = CSO_{m,t} + CSP_{m,t} \quad \forall m = 1,\ldots,M \quad \forall t = 1,\ldots,T \tag{B.17}$$

Equation (B.17) defines total consumption, based on consumption of own produce and market purchases.

$$\sum_{m=1}^{M} CNS_{m,tt} * fnc_{m,k} \geq fnr_k \quad \forall tt = 1,\ldots,TT \quad \forall k = 1,\ldots,K \tag{B.18}$$

Subsistence constraint (B.18) ensures that the total consumption is sufficient to meet food requirements every month between harvest and the start of the next cropping season.

$$\sum_{m=1}^{M} CNS_{m,TT} * fnc_{m,k} \geq fnr_k * (1 + |T| - |TT|) \quad \forall k = 1,\ldots,K \tag{B.19}$$

Subsistence constraint (B.19) ensures that the total consumption is sufficient to meet food requirements from the start of the next cropping season till the next harvest.

$$\sum_{nm=1}^{NM}\sum_{t=1}^{T} CNS_{nm,t} = 0 \tag{B.20}$$

Equation (B.20) ensures that non-consumable products are not consumed.

B.2.8 Equations determining variance of production

$$VAR = \sum_{n1=1}^{N}\sum_{n2=1}^{N}\sum_{l=1}^{L} cov_{n1,n2} * LAN_{n1,l} * LAN_{n2,l} \tag{B.21}$$

Equation (B.21) determines the variance of the production plan by standard formula.

$$VAR = VAP - VAN \tag{B.22}$$

Equation (B.22) is used to define the absolute value of the variance.

B.2.9 Soil nutrient balances

$$NAF_s = \sum_{i=1}^{I}\sum_{t=1}^{T} (sfc_{s,i} * IPA_{i,t}) \quad \forall s = 1,\ldots,S \tag{B.23}$$

Equations (B.23) till (B.28) are the components that make up the soil nutrient balance. Equation (B.23) calculates the amount of nutrients applied to the farm through fertilizer.

$$NLG_s = gli_s + glc_s * NAF_s \quad \forall s = 1,\ldots,S \tag{B.24}$$

Equation (B.24) calculates the amount of nutrients in applied fertilizer lost in gaseous losses.

$$BNF_s = \sum_{m=1}^{M} (sfh_{s,m} * sff_{s,m} * TPD_m) \quad \forall s = 1, \ldots, S \qquad \text{(B.25)}$$

Equation (B.25) calculates the amount of nutrients at the farm obtained from biological nutrient fixation.

$$NLH_s = \sum_{m=1}^{M} (TPD_m * sfh_{s,m}) \quad \forall s = 1, \ldots, S \qquad \text{(B.26)}$$

Equation (B.26) calculates the amount of nutrients removed from the farm in harvested products.

$$NUT_s = (snd_s - sne_s) * frs + NAF_s + BNF_s - NLG_s - NLH_s \quad \forall s = 1, \ldots, S \qquad \text{(B.27)}$$

Equation (B.27) calculates the soil nutrient balance after one cropping season. Positive contributions are made through deposits, added fertilizer and biological nitrogen fixation. Erosion losses, gaseous losses en harvested product contribute negatively to this balance.

$$NLF_s = \sum_{fm=1}^{FM} (TPD_{fm} * sfh_{s,fm}) \quad \forall s = 1, \ldots, S \qquad \text{(B.28)}$$

Equation (B.28) calculates the amounts of nutrients in harvested fodder products.

B.2.10 Constraints and balances of livestock production

$$H = \sum_{r=1}^{R} \sum_{f=1}^{F} AN_{r,f} \qquad \text{(B.29)}$$

Equations (B.29) till (B.31) define livestock production. These equations are only included in the analysis in Chapter 5. Equation (B.29) defines the total herd size maintained, which is the total of all animals kept under different feeding levels and rations.

$$\sum_{r=1}^{R}\sum_{f=1}^{F} AN_{r,f} * dom_{r,f,m} \leq TPD_m \qquad \forall\ m \in \{1, \ldots, FM\} \qquad \text{(B.30)}$$

Constraint (B.30) ensures that the total demand for fodder products is smaller than or equal to the production of fodder products.

$$TLG = \sum_{r=1}^{R}\sum_{f=1}^{F} AN_{r,f} * lwg_f \qquad \text{(B.31)}$$

Equation (B.31) defines the total annual gain in live weight of the total herd.

B.2.11 Restrictions on variables

All decision variables ≥ 0 (B.32)

VAR $\in R$ (B.33)

All decision variables included in the model should be greater than or equal to zero. In addition, the variable expressing total variance can take on all real numbers.

B.2.12 Mathematical Representation Objectives

Equations (B.34) till (B.37) are the mathematical descriptions of the five attributes or forms of the objective function that are used in the analysis.

$$GMN = \sum_{t=1}^{T}\sum_{m=1}^{M} ops_{m,t} * PRD_{m,t} - \sum_{t=1}^{T}\sum_{i=1}^{I} inp_{i,t} * IPA_{i,t} - \sum_{t=1}^{T} mwr_t * HWL_t - \sum_{t=1}^{T} awr_t * HAL_t \qquad \text{(B.34)}$$

The above equation (B.34) calculates the value of the possible objective *GMN*. This is calculated as the total market value of harvested product, less the market value of applied inputs, and used wage and animal labour, whereby costs of family labour are not accounted for.

$$SUS = NUT_{s='Nitrogen'} \qquad \text{(B.35)}$$

The above equation (B.35) calculates the value of the possible objective *SUS*. This is calculated as the resulting balance for the nutrient nitrogen at the end of the cropping season.

$$VAR = -VAN - VAP \tag{B.36}$$

The above equation (B.36) calculates the value of the possible objective *VAR*. This is calculated as the absolute value of the variance of the production plan.

$$LAB = \sum_{n=1}^{N} \sum_{t}^{T} \sum_{l=1}^{L} LAN_{n,l} * mlr_{n,t,l} \tag{B.37}$$

The above equation (B.37) calculates the value of the possible objective *LAB*. This is calculated as the total amount of labour spent on farming activities, including family and hired labour.

Summary

As a result of increasing population pressure, the average farm sizes in the savannah regions of West Africa have reduced. By consequence, farmers can no longer rely on fallowing to maintain soil fertility. For long farmers have therefore resorted to other methods. The most common on-farm strategies to cope with reduced fallow lengths are rotation of cereals with nitrogen fixing legumes and crop-livestock integration. The most important component of crop-livestock integration is the feeding of crop residues to livestock and the subsequent use of manure as fertilizer. At the same time, many farmers can no longer rely on farming as their sole source of income and diversify into off-farm income sources such as petty trading; local manufacturing jobs; or migrate (seasonally) to large urban areas. Hence, the coping strategies in the wake of increased population pressure are manifold, and the rural population is far from homogenous.

The aim of this study is to examine in detail three types of heterogeneity and their relationships with agricultural production. These three types of heterogeneity are: (1) heterogeneity in farmer goals and objectives, (2) heterogeneity in (on-farm) soil fertility resources, and (3) heterogeneity in crop-livestock integration. We thereby explore how differences in household characteristics and farming strategies relate to the three types of heterogeneity distinguished, and how this affects soil fertility levels.

These types of heterogeneity affect production (decisions) and farmer soil fertility resources in different ways. First, developed with the purpose of analysing the *ex ante* impact of policies and technologies on farmers’ soil nutrient use, bio-economic models frequently assume that farmers are homogenous in goals and preferences, i.e., their underlying utility function. Similarly, many studies on smallholder productivity and efficiency only include observable household characteristics and thereby implicitly assume that the relationship between household characteristics and farmer goals and objectives is homogenous. In neither type of study there is a clear reason to assume that such behavioural homogeneity holds. More importantly, ignoring farmer specific goals and objectives may lead to incorrect simulation outcomes from a bio-economic model, as well as biased estimates of efficiency or productivity. In both cases this could lead to ill-formulated policy recommendations. This is further investigated in this study.

Second, most studies focusing on productivity and efficiency in agricultural production assume farm size to be homogenous with respect to its soil composition, an assumption refuted by numerous field studies. Again, ignoring such information may lead to biased estimates and policy recommendations.

Third, livestock clearly plays an important role for production of manure, but manure production is not the main reason for households to keep livestock. Next to meat and other tangible benefits contributing to farm incomes in kind or in cash, several other non-tangible benefits, such as insurance and storing finances, play a role. The importance of these non-tangible preferences for keeping livestock may differ from one household to the other, giving rise to differences in the degree to which a farmer integrates crops and livestock.

These types of heterogeneity are further analysed in Chapters 2 till 5 of this study. Thereby use is made from various data sources from northern Nigeria. The data used includes farmers from villages in different agro-ecological zones in northern Nigeria, as well as villages characterized by different levels of market access. The villages also differ in population density, but levels of agricultural intensification are high throughout the region of study, with fallowing non-existent in nearly all locations.

The description of heterogeneity in farmer goals and objectives, and their effect on smallholder efficiency and on soil nutrient budgets is the subject of Chapters 2 and 3 respectively. Chapter 2 follows an explorative approach in documenting the various farmer goals and objectives. While arguable risk aversion and profit maximization are important attributes in farmer decision-making, other preferences and attributes may equally play a role. To capture such additional variables, a fuzzy pair-waise goal ranking is combined with a set of Likert scale questions. Principal component analysis is used to reduce these data into behavioural factors, i.e., the minimum set of underlying behavioural latent variables. We subsequently estimate technical and allocative efficiency levels by using Data Envelopment Analysis and analyse how these are related to farm characteristics and the identified behavioural factors. The models in which both intended behaviour and farmer characteristics are included give a significantly better fit over models in which only household characteristics are included. More importantly, next to expected effects of risk aversion, two other behavioural variables are identified that influence efficiency levels. These variables reflect the desire to be a successful farmer and the desire to fulfil subsistence demands from own production. On the other hand, the overall effects of these behavioural variables are small in relation to other observable household characteristics, and additional research should focus if and how agricultural policies should account for this heterogeneity.

In Chapter 3, the relationship between differences in goals and objectives and on-farm soil nutrient budgets is explored in more detail, by using a combination of multi-objective programming, multi-attribute utility theory and bio-economic modelling. The first part of the analysis establishes trade-off curves between the most common production attributes included in smallholder studies, i.e., optimisation of gross margins, labour use, risk levels and sustainable use of soil resources. The estimated trade-off curves reveal that farm plans aimed at optimising gross margins and, arguably, sustainable use of soil resources are more favourable, considering the nutrient balances, than those aimed at minimising production risks. In the second part of the analysis, by using multi-attribute utility theory, farmer specific weights for each of these attributes are identified. Risk aversion, operationalised through variance minimization, appears an important attribute in this study for many farm households with smaller land holdings. Subsistence production of cereals is dominant in such farm plans that lead to negative soil nutrient balances, especially for potassium. Farmers who place a large importance on gross margins in their utility function are likely to benefit most from policies aimed at enhancing profitability through improving the functioning of markets. The large group of risk averse farmers will have the largest immediate gain in utility from policies and technologies aimed at lowering production risk in high-value crops. Additional policies aimed at creating a stronger market–oriented production by the least-endowed farm households could play a role in reducing intensity of soil fertility mining. Then, the efficient cropping pattern shifts (partially) from cereal cropping to high value crops, associated with higher input use.

In Chapter 4 it is analysed how heterogeneity in soil fertility resources at farm level affects maize and sorghum production, and measures of technical efficiency for these crops. While arguably crop production is dependent on natural soil fertility levels, this is not always taken into consideration in production function estimations. Two variables that can easily be derived from household production surveys are introduced as proxies for on-farm heterogeneity in soil fertility. Next to these proxies, detailed soil fertility data at village level is included to account for differences in soil fertility levels between villages. The results show that the used soil fertility variables have significant effects on production, although not always of the expected sign. Secondly, the inclusion or omission of such soil fertility variables plays a critical role in testing for the presence of inefficiency. In the case of maize production, inefficiency is no longer observed after inclusion of the soil fertility variables. Finally, variation in labour availability is an important determinant of the inefficiency found in sorghum production. The findings highlight the need to further develop and include proxies for on-farm soil fertility heterogeneity in smallholder efficiency and productivity studies.

In Chapter 5 it is investigated how preferences in non-tangible benefits of keeping livestock relate to differences in herd size and crop choice at different types of farms. Integrating crops and livestock is widely advocated as a method to maintain soil fertility levels through increased use of manure. On the other hand, there are many other benefits of keeping livestock, such as insurance and storage of finances, in addition to manure production. The role of such non-tangible benefits could differ across farms, thereby driving apparent differences in observed levels of crop-livestock integration. First, a bio-economic simulation model is used to identify, at different farm types, the relationships between preferences for non-tangible benefits, optimal herd size and crop choice. The simulation outcomes show that optimal herd size increases for non-tangible benefits, though herd size decreases again for increased importance of tangible benefits, i.e., liveweight production. Furthermore, the results from the model suggest that for increasing labour supply, herd size decreases due to a shift into vegetable cultivation and consequent reduction of on-farm fodder supply.

Second, a novel method to measure non-tangible benefits empirically is introduced in this chapter. This measurement is done by calculating the difference between simulated herd size at maintenance levels, given on-farm fodder supply, and actual herd size observations. A regression analysis shows that farm households well-endowed with farm and labour are more likely to maintain (too) large herds, possibly as a mechanism to store finances. Consequently, these farmers also use more manure. It shows that herd size increases demand for fodder products, while there is additional evidence that manure use benefits cereal production, but does not benefit other crops. Hence, similar to the results in Chapter 3, these results suggest that specific policies and technologies are needed to enhance use of manure at the least-endowed farm households.

Finally, in Chapter 6 the wider implications of the research findings and the methods used are discussed. More specifically, three topics are discussed in more detail. First, it is discussed how research should further address heterogeneity in goals and objectives in various types of study. It is thereby argued that experimental field research methods could potentially further improve the accuracy of latent variables, including the newly identified ones in Chapter 2. Furthermore, such variables could further shed new light in other agricultural or development studies at smallholder level, such as (dis-)adoption studies. Second, it is discussed how simulation models can be improved for more accurate design of policies to promote growth at smallholder levels. Both the inclusion of heterogeneity in farmer goals and objectives, as done in this study, and the use of robust optimisation methods to account for data uncertainty thereby play an important role.

Finally, the implications of this research for the enhancement of sustainable use of soil resources in the savannah regions in Nigeria, and Africa in general, are discussed. Most importantly, the results in Chapter 3 and 5 suggest that mostly well-endowed farmers tap into markets for high-value crops, and thereby use more organic and inorganic inputs. Hence, research should focus on how production, and sustainable use of soil resources, at the least-endowed farmers can be enhanced further. This can be partially achieved by developing technologies that reduce the risk in the cultivation of high-value crops and policies aimed at bringing the least-endowed to the market. Potentially this can be achieved through cooperative agreements between farmers, but little is yet known if and how such agreements can play a role. This can be further investigated by combining bio-economic simulation models and methods from cooperative game theory.

Samenvatting

Als gevolg van bevolkingsgroei is de gemiddelde oppervlakte van het land van kleinschalige boerenhuishoudens in de savanneregio's van West-Afrika gereduceerd. Daarom kunnen huishoudens niet langer gebruik maken van braaklegging om bodemvruchtbaarheid in stand te houden. Al sinds geruime tijd gebruiken boeren andere methodes. De meest voorkomende methodes zijn het roteren van graangewassen met stikstofbindende vlinderbloemigen en het integreren van gewas- en veeproductie, m.a.w. gemengde productie. De belangrijkste component van een gemengd productiesysteem betreft het gebruik van plantresten als voedsel voor vee en vervolgens het gebruik van mest om bodemverarming tegen te gaan. Tegelijkertijd kunnen veel boeren niet langer vertrouwen op de inkomsten uit landbouw als hun enige bron van inkomsten. Daarom diversifiëren veel boeren hun inkomstenbronnen, ook in niet-agrarische sectoren zoals kleinschalige handel en productie, terwijl anderen tijdelijk migreren naar stedelijke gebieden. Boeren reageren dus op verschillende manieren op de gevolgen van bevolkingsgroei, en als gevolg daarvan is de plattelandsbevolking in Afrika verre van homogeen.

In deze studie worden drie types van heterogeniteit, en hun relatie tot landbouwproductie, onderzocht. Deze drie types zijn: (1) heterogeniteit in doelstellingen; (2) heterogeniteit in bodemvruchtbaarheid tussen velden op boerderijen; en (3) heterogeniteit in gemengde bedrijven. Daarbij verklaren we hoe verschillen in huishoudkarakteristieken en productiestrategieën zich verhouden tot deze types heterogeniteit, en welk effect dit heeft op het beheer van bodemvruchtbaarheid.

De effecten van deze onderscheide types heterogeniteit op productiestrategieën en bodemvruchtbaarheid zijn verschillend. In de eerste plaats speelt heterogeniteit in doelstellingen een belangrijke rol in bio-economische simulatiemodellen. Zulke modellen, die worden gebruikt om het effect van beleid en nieuwe technieken op productie en bodemvruchtbaarheid in huishoudens te bepalen, maken vaak een aanname dat boeren homogeen zijn met betrekking tot hun doelstellingen, d.w.z. hun onderliggende nutsfunctie. Daarnaast worden verschillen in efficiëntie en productiviteit van boerenhuishoudens vaak gerelateerd aan karakteristieken van het huishouden, zoals leeftijd en opleidingsniveau. Daarbij wordt impliciet aangenomen dat de relatie tussen de (productie-)doelstellingen van een huishouden en huishoudkarakteristieken homogeen is. Echter, de *a priori* aanname dat boeren homogeen in doelstellingen zijn is niet gerechtvaardigd. Bovendien kan het negeren van verschillen in doelstellingen leiden tot vertekende uitkomsten van een bio-economisch simulatiemodel, en kunnen ook de schattingen in een efficiëntiestudie vertekend zijn. In beide gevallen kan dat leiden tot onzorgvuldig geformuleerd beleid. Dit wordt verder onderzocht in deze studie.

In de tweede plaats wordt in veel efficiëntie- en productiviteitsstudies de aanname gemaakt dat de bodemkwaliteit op een boerderij homogeen is. Tegelijkertijd laten andere studies zien dat er vaak grote kwaliteitsverschillen zijn tussen verschillende velden op een boerderij. Het niet meenemen van zulke verschillen in een efficiëntiestudie kan wederom leiden tot vertekende resultaten.

In de derde plaats speelt vee vanzelfsprekend een belangrijke rol in de voorziening van organische meststoffen. Echter de productie van zulke meststoffen is niet de belangrijkste reden voor boeren om vee te houden. Naast materiële motieven zoals mest, vlees en zuivelproductie, houden huishoudens vee voor niet-materiële redenen zoals verzekering en als mechanisme voor financiering en waardeopslag. Het belang van zulke niet-materiële redenen kan verschillen tussen boeren, als gevolg waarvan de mate waarin boeren gewas- en veeproductie mengen ook kan verschillen.

Deze drie types van heterogeniteit worden verder geanalyseerd in de Hoofdstukken 2 tot en met 5. Daarbij wordt gebruik gemaakt van verschillende datasets van Noord-Nigeria. Deze datasets bevatten gegevens van boeren in dorpen uit verschillende agro-ecologische zones, waarbij deze dorpen daarnaast verschillen in de afstand tot markten. De dorpen verschillen ook in bevolkingsdichtheid, maar niveaus van landbouwintensivering zijn hoog in de gehele regio, en braaklegging komt in geen van de dorpen meer voor.

De beschrijving van heterogeniteit in doelstellingen, en de effecten hiervan op productie-efficiëntie en bodemvruchtbaarheid worden in respectievelijk Hoofdstuk 2 en 3 besproken. De methode die wordt gebruikt in Hoofdstuk 2 heeft tot doel om, naast belangrijke doelstellingen als risicoaversie en winstmaximalisatie, de overig doelstellingen te beschrijven die een mogelijke rol spelen in de productiebeslissingen van kleinschalige boerenbedrijven. Om deze doelstellingen te bepalen wordt een ordeningsmethode (fuzzy pair-wise ranking) gecombineerd met het stellen van een aantal vragen, waarvan de uitkomsten worden gemeten op een Likert-schaal. Daarna wordt gebruik gemaakt van datareductie om de minimale set van onderliggende latente variabelen te bepalen. Vervolgens worden technische en allocatieve efficiëntieniveaus bepaald door het gebruik van een niet-parametrische schattingsmethode (Data Envelopment Analysis). Ten slotte worden de efficiëntieniveaus gerelateerd aan huishoudkarakteristieken en de geïdentificeerde latente variabelen die de doelstellingen meten. De analyses waarin beide types variabelen worden opgenomen geven een significant betere verklaring van de geobserveerde variatie in efficiëntie. Naast de verwachte effecten van risicoaversie worden ook effecten waargenomen van twee andere latente variabelen. Deze variabelen meten respectievelijk de wens om zelfvoorzienend te zijn in voedselproductie, en de wens om een succesvolle boer te zijn. Echter, de effecten van deze variabelen zijn slechts klein in vergelijking tot andere huishoudkarakteristieken. Verder onderzoek is daarom noodzakelijk om te bepalen of en hoe landbouwbeleid rekening moet houden met zulke heterogeniteit.

In Hoofdstuk 3 wordt de relatie tussen heterogeniteit in doelstellingen en bodemvruchtbaarheid onderzocht. Hiervoor wordt een bio-economisch simulatiemodel gecombineerd met optimalisatiemethoden voor meerdere doelstellingen (in het bijzonder multi-objective programming en multi-attribute utility theory). In het eerste deel van dit hoofdstuk worden curves bepaald die de uitruil (trade-off) tussen verschillende doelstellingen inzichtelijk maakt. Dit wordt gedaan voor de meest gebruikte doelstellingen in analyses van kleinschalige bedrijven, namelijk winstmaximalisatie, minimalisatie van productievariantie, maximalisatie van duurzaam gebruik van bodems, en minimalisatie van gebruik van arbeid in het productieproces. De curves tonen aan dat productiestrategieën gericht op winstmaximalisatie en, voor de hand liggend, duurzaam bodemgebruik het meest duurzaam zijn in tegenstelling tot strategieën gericht op het minimaliseren van productievariantie. Hierbij wordt duurzaamheid bepaald aan de hand van een balansbepaling van macronutriënten in de bodem.

In het tweede deel van dit hoofdstuk wordt voor elke boer een set gewichten bepaald die zijn individuele preferenties voor deze doelstellingen weergeeft. Het minimaliseren van variantie, m.a.w. risicoaversie, speelt een belangrijke rol in veel huishoudens met kleinere landoppervlakten. De productie van graangewassen domineert in zulke strategieën waarbij de nutriëntenbalansen voornamelijk negatief zijn, in het bijzonder voor fosfor en kalium. Boeren, die een sterk belang hechten aan winstmaximalisatie, zullen de meeste baat hebben bij beleid dat het functioneren van markten bevordert. De grote groep van risicoaversie boeren zullen de meeste baat hebben bij beleid en technologieën welke hun blootstelling aan productierisico's vermindert, in het bijzonder voor gewassen met een hoge marktwaarde zoals groentes. Daarnaast kunnen ook de armste huishoudens baat hebben bij beleid dat hun oriëntatie op marktproductie verstevigd. Dan verschuift het productieplan gedeeltelijk van graangewassen naar gewassen met een hoge marktwaarde en, met een hoger gebruik van meststoffen, nemen de nutriëntenbalansen toe.

In Hoofdstuk 4 wordt onderzocht hoe heterogeniteit in bodemvruchtbaarheid op een boerenbedrijf de efficiëntieniveaus van maïs en gierst beïnvloedt. Hoewel productie van deze gewassen afhangt van bodemvruchtbaarheid, wordt dit niet altijd in efficiëntieschattingen meegenomen. Daarom worden er twee variabelen geïntroduceerd die de verschillen in bodemvruchtbaarheid op een bedrijf benaderen. Daarnaast worden gedetailleerde gegevens over gemiddelde verschillen in bodemvruchtbaarheid tussen dorpen in de analyse meegenomen. De resultaten tonen aan dat er significante effecten van bodemvruchtbaarheid op productie zijn. Bovendien spelen deze variabelen een belangrijke rol bij het identificeren van inefficiëntie. In het geval van maïsproductie is er niet langer een bewijs van inefficiëntie, na toevoeging van deze variabelen. In gierstproductie verklaart de beschikbaarheid van arbeid de waargenomen inefficiëntie. Deze resultaten tonen de noodzaak aan voor verdere ontwikkeling en perfectionering van variabelen die verschillen in bodemvruchtbaarheid benaderen en kunnen worden opgenomen in efficiëntiestudies.

In Hoofdstuk 5 wordt onderzocht hoe preferenties voor niet-materiële aspecten van het houden van vee, zoals veehouderij als verzekerings- of financieringsmechanisme, relateren tot kuddegrootte en gewaskeuze op verschillende types bedrijven. Terwijl het mengen van gewas- en veeproductie wordt aanbevolen als een belangrijke methode om bodemvruchtbaarheid in stand te houden, is productie van organische mest niet de meest belangrijke reden voor huishoudens om vee te houden. Bovendien kunnen verschillen in preferenties voor niet-materiële aspecten leiden tot verschillen in kuddegroottes en in de mate waarin gewas- en veeproductie wordt gemengd. In het eerste deel van dit hoofdstuk wordt een bio-economisch simulatiemodel geconstrueerd om de relaties tussen niet-materiële opbrengsten, kuddegrootte en gewaskeuze te bepalen. De uitkomsten van dit simulatiemodel laten zien de kuddegrootte toeneemt voor toenemende preferentie voor niet-materiële opbrengsten, en afneemt voor toenemende preferentie voor materiële opbrengsten, d.w.z. vleesproductie. Daarnaast laten de modeluitkomsten zien dat voor toenemende beschikbaarheid van arbeid, het aandeel van gewassen met een hoge marktwaarde in de productiestrategie toeneemt, en de optimale kuddegrootte afneemt. Dit laatste komt door een afname in beschikbaar voedsel voor vee zoals plantresten van graan en vlinderbloemigen.

In het tweede deel van dit hoofdstuk wordt een nieuwe methode geïntroduceerd om de preferentie voor niet-materiële opbrengsten van veeproductie te meten. In deze methode wordt eerst bepaald, op basis van de gerealiseerde productie van plantresten, welke kuddegrootte op onderhoudsniveau, dus zonder gewichtstoe- of afname, in stand kan worden gehouden. Daarna wordt de afwijking tussen deze kuddegrootte en de werkelijke kuddegrootte bepaald. Een kuddegrootte die groter is dan de kuddegrootte op onderhoudsniveau geeft een indicatie voor preferentie voor niet-materiële opbrengsten. De resultaten laten zien dat leeftijd, opleidingsniveau en bodemkwaliteit verschillen in deze afwijking verklaren. Daarnaast neemt deze afwijking ook toe voor bedrijven waarvan de landoppervlakte en het huishouden groter zijn. Bovendien blijkt uit de analyse dat zulke bedrijven ook meer gewassen met een hogere marktwaarde verbouwen. De afwijking, en dus het belang van niet-materiële opbrengsten, hangt daarbij hoogstwaarschijnlijk af van opbrengsten uit financiering en waardeopslag. Tevens gebruiken zulke bedrijven meer organische meststoffen, die een klein, maar significant, effect hebben op productie van graangewassen. Dus, vergelijkbaar met de resultaten in Hoofdstuk 3, zijn er specifieke technologieën en beleid nodig om het gebruik van organische mest te stimuleren bij de armste huishoudens, d.w.z. huishoudens met de minste beschikbaarheid van land- en arbeid.

Ten slotte worden in Hoofdstuk 6 de implicaties van de resultaten en de bevindingen van de gebruikte methodologie besproken. In het bijzonder worden drie onderwerpen behandeld. In de eerste plaats wordt besproken hoe heterogeniteit in doelstellingen en preferenties verder moet worden meegenomen in onderzoek naar kleinschalige boerenhuishoudens. Daarbij wordt besproken hoe onderzoeksmethoden uit de experimentele economie kunnen worden gebruikt. Bovendien kunnen betere metingen van latente variabelen, zoals gevonden in Hoofdstuk 2, potentieel ook betere verklaringen geven voor ander waarnemingen in kleinschalige bedrijven in Afrika, zoals (dis-)adoptie van nieuwe landbouwtechnieken.

In de tweede plaats wordt besproken hoe simulatiemodellen, zoals de modellen gebruikt in Hoofdstukken 3 en 5, kunnen worden verbeterd zodanig dat meer nauwkeurige resultaten worden verkregen, en daarmee ook het ontwerp van beleid ter stimulering van duurzaam bodemgebruik verbeterd wordt. Zowel het meenemen van heterogeniteit in doelstellingen, als het gebruik van robuuste optimalisatiemethodes, om te corrigeren voor mogelijke fouten in de parameters in het model, spelen daarbij een belangrijke rol.

In de laatste plaats worden de bevindingen uit dit onderzoek met betrekking tot het stimuleren van duurzaam bodemgebruik besproken. De resultaten in Hoofdstuk 3 en 5 tonen aan dat de relatief rijkere bedrijven, dat wil zeggen bedrijven met meer land en arbeid beschikbaar, particperen in de markten voor gewassen met een hoge marktwaarde, zoals groentes. Daarbij gebruiken zij zowel meer organische als inorganische meststoffen. Dus onderzoek moet zich vooral richten op hoe productie en duurzaam gebruik van bodems kan worden verbeterd onder de armste bedrijven. Dit kan worden bereikt door het ontwikkelen van technieken waarbij de variantie van opbrengsten bij gewassen met een hogere marktwaarde vermindert. Daarnaast is beleid nodig om de armste bedrijven in de markt te laten participeren. Mogelijk kan dit worden bereikt door coöperatieve afspraken in productie te stimuleren. Echter meer onderzoek is nodig naar de exacte opbrengsten en kosten in zulke afspraken en hoe duurzaam bodemgebruik hierdoor kan worden gestimuleerd. Om dit te onderzoeken kunnen bio-economische simulatiemodellen verder worden gecombineerd met methodes uit de coöperatieve speltheorie.

Saboda yawan karuwan mutane, girman gonaki a cikin dajin Africa ta yamaci sun ragu sosai. Shi ya sa manoma baza'su iya barin gonakin su babu noma don su kara karfi. Lokaci da yawa manoma basu bidi sabobin dubaru dan su kara karfin tashin gonakansu ba. Dubaran wada suka fi aikatawa domin barin gonakinsu babu noma, shine shipka masu kanu, sa'anan salati da kamat'su, masu kama taki a cikin kasa, kuma da a gama noma da kiwo. Abin mai ma'ana a gama noma da kiyo, shine sai a bar bisashe abinda ya rage saura a nome, kuma bisashe suna yin taki mai anfanin noma sosai. Cikin wanan lokaci, manoma dayawa arzikin noma bazai ishesu ba, sai sun gama da wasu aikace aikace kamar karamar sana 'a, aikin hannu ko su tashi bida a chikin birane. Wannan ne yas'sa ana koyi dubaru iri iri da mutane daji su ke iya anfani da su, kowa da dubaran sa.

Manufa wanan tadi shine lisafi da dubaru iri uku da zasu amfani noma. Wanan irin dubaru sune: (1) abinda manoma suka nufa da bida su domin samu, (2) dubara ta wajen kara karfin kasa don noma, (3) dubara ta gama noma da kiyon bisashe. Zamu bincika muga kakan da iyalin manoma zasu sakewa da kakan da karfin kasa zata karu.

Da farko, domin ana yin su ne da duban anfanin da manoma suke yi da takin, bide-bide bisa noma daji yana tsamanin manoma na neman abu iri guda wajen neman albarka aikin kasa. Kuma, karatu dayawa don akai bisan kananan ma'aikatan gona su na aiki da abinda su ka gani a bisan iyalan manoma, suna tsamani komin da iyalan monoma dake nema iri guda ne.

Babu karatun da ya goda wanan tsamani dadai ne. Kari da kari, rashin aiki da dubaru daban daban chikin wanan karatun, shi ke sa ba'a samun dadai chikin tsamani abinda noma yake anfani. Irin wanan ya na sa a samu mugun gurgunta. A gaba muna diba wanan abu.

Na biyu, tadi masu yawa bisan anfani kasa da karfin noma na tsamani girman gona da albarka kasa iri guda ne ko ina, amma wanan karatu dayawa sun karyantashi. Manta da wanan ne ke sa anan bada Magana bisa noma da siyasa noma ba mai kyau ba.

Na uku, kiwo na anfani sosai wajan bada taki ga gona, am'ma ba shi ke sa manoma suna kiwo ba. Game da nama da wasu anfani da suna samu a cikin bisashe, akoyi wasu anfani da basu ganuwa, kamar adani da ajiwa domin in gobe tabaci.Karfin da kowane manomi ya ke ba wadanan afanin shi ke sa kowane manomi na sa irin nashi karfi chikin kiwo bisashe. Irin wadanan dubaru muna dubansu a lamba 2 zuwa 5 na wanan karatu. Muna aiki da rahotanin da muka samu daga adercin najeriya. Rahotanin su zo daga manoman garuruwa iri iri na adercin najeriya, da masu zuwa kasuwa daban daban. Garuruwa na daban daban bisa yawan mutanen su, ama noma na da karfi ko ina don akara yin karatu, kuma babu inda a ke barin kasa babu noma yanzun.

Gwadia manufofin manoma daban daban, da abinda yake kawo wa a biyan girman gonaki da neman arziki zai shafi nu’uma 2 da 3 kowane. A ticin nu’uma ta 2 muna neman abinda yake sa manoma ke doka wasu manufofi daban daban bisa aikin daji.

Koda shike sunfi bada hankali da bida riba sosai, a koyi wasu abubuwan dake shiga lisafi.

Wajen bida wanan abubuwan, muna yiwa makaho tambayoyi biyu-biyu da ake cema Waise. Amsa da aka samu za a rage su wajen duban yanda manoma suke bayana.

Sa’anan mu dibi karfin su a chikin lisafin da ake cema Development Data Analysis don mu ga yanda suke bayana yanda gonakai suke, da yanda manoma suke dokan wasu niyya.

Wanan lisafin yafi lisafin da a ke aiki da girman gona da iyali kadai. Mafi girma, bayan aikin da’ da tsoron bana, abu biyu ne mun samu da ke kara amfanin noma. sune bidan zaman manomi mai ciyedda kansa da mai samu isa kanshi. Ama wanan ya dadda karamta bisa a binda ake gani a chikin iyalan manoma, sai an kara karatu bisa yanda siyasa noma zata gwaru.

Chikin shapta na 3, muna duban abinda ya raba niyya da arzikin takin gona, da dubarun dabam dabam na aikatawa da lisafi bisa aikin daji. Wurin numa duban yadda adinda ya gama noma da bida riba sana’a, chikin hankali, da amfani da kasan da ba’a bata ta ba. Wanan aiki ya gwada da noma yana bada riba dayawa, kuma suna kula da addanan karfin kasa, bisa bida abinci da rage ‘bashin shekara. Chikin shaida ta 2 na wanan lisafi, tareda dabaru iri iri, mun gane da yadda manoma suke aiki da kowane dubara. Tsoron bana, yadda a ke rage shi, yana da karfi dayawa ga masu kakanan gonaki.. Noma tsaba abinci ya fi yawa a chikin irin wanan manoma, shi ke sa kasa ta rague albarka, harma ya rage karfin gishirin. Manoma masu sa riba gaba chikin niyya su iya samu albarka shiyasa ta ‘kara anfani a chikin kasuwa. Manoma masu tsoron bana su ke cin riba chikin shi yasa mai aiki da rage tsoron girman albarka gona. Karin samun abinci ya sa karfin kasa ya ragu. Shi na sa kari albarka noma shi kara anfani, tareda karin taki.

A chikin chapta na hudu(4) muna duban yadda kara karfin kasa zaya sa massara da hatsi su karu, ya awna riba bisa wanan girbi. Don yawan sanu yana daga karfin kasan ne, ba kullum ba ne a ake aiki da shi chikin tsamani yawan albarkun noma.

Abu biyu ne da so ka samu daga noman gidaje sun shiga cikin iri irin albarka kasa. Tare da wanan, tarin sani bisa albarkan kasa ya shiga chikin banbanta garuruwa bisa anfani kasan su. Wanan ya gwada da arziki kasa ya na kara albarka noma, koda yake, ba ko da yaushe ba ne. Na biyu, karin ko ragin chikin duba kasan noma ya na sa bada mugun al amari bisa samu rashin anfani. Bisa noma massara, a na barin samu rashi in an kulla da arzikin kasa. A karshe, samun kasa mai iya noman dawa ya na rage samun albarka a chikin noman dawa. Shine ya gwada dolle aiki da wadanan munana chikiin karatun bisa samun albarka chikin noman kananan manoma.

A cikin chapta na biyat (5), a na diba kakane zaben kiwon bisashe ba cikin bida riba ba, ya ke bisa girman gona da irin noman da a ke yi. Noma da kiwo tare anan yin shi a koina saboda kara karfin kasa, saboda takin da a ke kara ma ta. Wani waje, akanyi riba dayawa cikin kiwo, kanan ajiya kudi, tare da albarka taki. Anfani wanan dubara yana da daban-daban, shi ke sa a na gamin girman kiwo daban-daban. Ana aiki da wani tsamani sana'a bisa rai, don a samu, chikin gandu iri iri, abinda ke gama girma kiwo, girma gona da zabe shipka. An gane da garke mai girma in da ake bida anfani wanda ba na kudi ne ba, kananan garke in da a ke bida riba kudi maza maza. Kuma da aiki ya karu, kiwo ya na raguwa saboda raguwan abinci bisashe.

Na biyu, muna aiki da wata sabuwa dubara ta awon riba wadda ba ta kudi ba. Wanan awo a na yin shi tsakanin tsamani girma garke chikin gona babu shipka, da girma garke da ake gani a gaskiya. Mun gane da noma da kiwo tare da baban garke domin ajiya kudi ne. Shi ke sa suna aiki da taki mai yawa. Shine ke sa girman garke na kara neman abinci bisashe, suma suna bada taki don kara albarka noman abinci, aman ba wasu noma ba. Haka, kuma abinda mun gane a chapta na uku(3), wanan ganuwa yasa sai da siyasa da zamani don karin karfi taki kiwo.

A karshe, chikin chapta shidda (6), ana duban abinda bida ta bada da yanda an kai wanan bida. Chikin abu uku ne an duba sosai. A warawa, kakane bida zata dibin nufa iri iri chikcin wasu karatu. Yana cewa yanda inda ake wanan bida ya na kara karfin abinda a ke samu, kuma wadanan na chapta biyu(2). Zuwa gaba, irin wana bide-bide suna kara ma wasu aiki bisa noma da tashin arziki chikin manoman daji, kama karatu bisa gado. Na biyu, ana duba kankane wanan bida ke sa kiyaya ta kara albarka noma wajan kakana manoma. Douka aiki da iri iri niyya manoma, cikin wanan karatu, da aiki da gwanita mai karfi don tara labarin ya na da rashin daidai, suna da anfani da yawa.

A karshe, wannan karatun binchike karin hanyoyin albarku kasa a cikin yamanci Najeriya da Africa gaba daya, an ji maganan su. Mafi ni‘ima, abinda aka samu chikin chapta 3 da 5 na gwada manoma masu anfani da kasuwa da manyan gonaki, suna aiki da taki ko abinci da yawa. Shi yasa, bida ya kamata su nemi shin, mi ya sa noma da aiki da albarka kasa da imani, zai karu zuwa gaba. A na iya samun wanan chikin aiki da shi yasa da ke rage noman don kasuwanci. A na iya bada karfi wajen gana manoma tsakanin su don su tara arzikinsu wuri guda, aman ba a sani ba ko wanan kankani zashi anfani su. A na iya duba wanan tare da duban noma daji da kasuwanci iri iri da gama manoma chikin wata wassa taraya.

Acknowledgements

Africa, with its enormous diversity and complexities, has pulled me back ever since my first visit to the continent in 1997. When moving to Nigeria in 2004, for three years, I hoped that my work would somehow contribute to improve the wellbeing of the millions of Africans who struggle for survival, day in, day out.

Isyaku Mohammed did just that. On November 30th, 2007, he was selling water on the streets in Bichi town, along the main road between Kano and Katsina. About 10 years old and without funds to pay for his school fees, he had to make ends meet for himself, and his family, by trading in the streets. On that day, in the scorching heat just after noon, a thirsty man called him on the other side of the road. With a new business opportunity in sight, he ran across the street. Being just a child, he did not watch for traffic. Isyaku was hit by a car.

On that same day I completed three years of data collection in Nigeria, two weeks later Marloes and I would fly back to The Netherlands, for good. I had just finished a participatory research meeting in Sauta Janbuge. Only one meeting was left to be done, on the next day. Most enumerators and local collaborators had been thanked. Next to me, George Ucheibe sat relaxed; he had almost completed all data entry by that week. Field assistant Zachariah Jamagani, with the end in sight, was sitting at the back of the car, also relaxed. Nevertheless, we were still in a rush to make it to Kano quickly. Friday afternoon prayers would start soon and large masses would congregate on the roads, walking to the nearest mosque. Kano's roads would become impenetrable for two hours. We slowed down in Bichi town, already crowded. Then, all of a sudden, a young boy emerged from the crowd and ran across the road. It was too late to stop.

Isyaku was hospitalized in the local hospital. But the doctors, it turned out, were incapable of getting to grips with the serious internal trauma he had suffered. Two days later, with Isyaku's condition quickly deteriorating, he was rushed to the Kano university hospital. There, a last-minute operation saved his life.

That grim day became a sour end to three wonderful years in Nigeria. In the end this research will hopefully contribute to the well being of Africa's rural population, but that day it nearly took a life. Isyaku deserves to be mentioned first in this place, even though the hardship he, and his family, went through in those days can hardly be referred to as an acknowledgement.

Ironically, Isyaku was lucky to have been hit by us and not just another truck driver. It were the IITA-doctors in Ibadan who summoned Isyaku to be relocated to Kano. But the ambulances in Bichi did not have any petrol, and he was transported to Kano with an IITA car. IITA covered all medical expenses and in the immediate aftermath local IITA-staff Adebayo Adebanjo, Musa Abubakar (ILRI) and Muhammed Umar did a wonderful job in arranging the medical care and handling all formalities.

Indeed they arrived on the scene quickly, a symptom of a well-functioning small research station. It should be mentioned. Without them, the implementation of the field research activities used in this thesis would have been hopelessly more complicated. Muhammed Umar, in charge of the daily smooth running of the station; Adebayo Adebanjo for providing money when we were short of it; Shakiru Apenna for fixing 234 CT 221 when it broke down again (and getting angry with me when I had failed to clean the car after intentionally, but unnecessarily, testing its 4x4 performance on Kano’s mud roads); John Oyekanmi, Idris Lamidi and Onu Anyabe Yusuf for taking us to Zaria, Niger, Kaduna, Nguru and Yankari; Andrew Ibrahim for fuelling the car, responsible for the daily struggle against the dust in the offices and struggling with the immigration officials at the airport for us; Helen Matthias, Elizabeth Musa and Apollonia Onyechere for running the secretary office; Matthias Ugwuja for his assistance in our quest for furniture; and Tibidawe Ibrahim, Habila Mamman, Ibrahim Mijinyawa, Musa Iliyasu for their help at various other points in time.

Much of the data used in this thesis was collected by village-based enumerators. Tijani Wada in Kiru; Kabir Shuaibu in Bindawa; Khalil Mohammed in Kaita; Musa Umar in Kunchi; and Yusuf Mohammed in Warawa; all did a great job in visiting the farmers regularly and, without getting them bored, retrieving so much valuable information. In addition, the IITA’s research associates in Zaria, Lekan Tobe, Sadiq Bako and Ige collected much of the data in Kaduna State, under the supervision of Nicoline de Haan. Furthermore, the initial help in setting up the field work the help of Aminu from the Katsina ADP and Tsoho from the Kano ADP are much appreciated.

Thanks to the help of many IITA-staff I was able to quickly draw up my research plans after arrival at IITA. First, and foremost, the discussions with Ousmane Coulibaly, Victor Manyong, Steffen Abele and David Chikoye in the first months of our stay in Nigeria were of great importance to me in shaping this research. Thanks to Chris Legg and Kai Sonders for helping me out with GIS-data and the maps in this thesis. During regular stays in Ibadan the discussions, both in office hours and at night in I-house, with Linus Franke, Nicoline de Haan, Bas Harbers, Jan Diels, Annitta Tipalda, Arega Alene, Alexander Schoening, Kai Sonders, and all other who I forget to mention helped me a lot in getting the overview of the work done by IITA in the past, research gaps and learning the workings of the organisation. Apart from that, you made the stays in Ibadan, much more fun.

Thanks to some initial perseverance of Marloes and me, a coffee break saw the light at the IITA office in Kano, and following the latest reports is still a well-nourished institution. We brought a coffee machine from Holland and David Chikoye started to bring coffee from Cameroon regularly. It quickly became institutionalized with Festo Massawe, Satoru Muranaka, Alphonse Emechebe, Bir Singh, Boukar Ousmane, Tahirou Abdoulaye, Alpha Kamara and Hakeem Ajeigbe regularly passing by to discuss basically everything from administrative issues in Kano station, via agricultural research and Nigerian politics to Premier League football. The friendships I developed with you made me and Marloes feel at home in Kano quickly, and shaped our stay in Nigeria.

Finally, many others in Nigeria were of great help to me, directly or indirectly, in carrying out this research. In particular, I want to thank Joseph for cleaning our house daily, maintaining the garden and ironing my shirts; Captain David Sewell for taking us on some memorable flights across Nigeria and Benin in IITA’s aircraft; Cathelijne van Melle and Peter Boons for making our stays in Cotonou so enjoyable. Joep and Jitske for letting us stay in their house when we arrived in Ibadan in 2004 and instantly suffered from food poisoning on Christmas day; and finally Steve at KLM in Kano for waiving 150 kg of excess luggage, much of it scientific books, at the night of our return to The Netherlands.

Back in The Netherlands, Ruerd Ruben saw something promising in my assignment with IITA, and the department of Development Economics in Wageningen were kind enough to seat me in their group for one and a half year. More importantly, the department was willing to bear the costs for the remaining courses I needed in order to complete my TSP, as well as to cover travel expenses to two conferences. That said, the most valuable reward in this period has been the participation in a stimulating scientific environment, through informal discussions during coffee breaks and formal ones during regular seminars or the frequent reading groups. So thank you Kees, Marrit, Pan, Erwin, Rein, Nico, Maarten, Lonneke, Aifa, Benigno and Ingrid for your comments and suggestions on my ongoing work and/or for the many, (scientific or not) discussions, during coffee breaks; the monthly get-together in Looburg; and during our departmental trip to Ghent. A special thanks to Roselia, Fred and Chen with whom I shared room 3111 at various points in time and for the great discussions on research troubles; the joys of doing a PhD; the not so joyful issues related to doing a PhD; and other great discussions!

Most helpful to me in this past period in Wageningen has been Rob Schipper. Rob not only patiently read my pieces of writing a great many times, whether it be the initial research proposals or the chapters in this thesis, he also arranged some financial details during my stay in the past 18 months. Rob was of great help both in discussing the broad lines of each chapter, and working with me to the final drafts. Once at, or nearly at, that stage Arie and Herman, meticulously read these drafts. Even after my own careful reading, they were always able to produce a great amount of final comments and suggestions, and thereby helped me a great deal in improving the quality of the chapters to a higher level.

George Ucheibe had been driving with me before on that fateful day in November 2007. Likewise, Zachariah Jamagani had been assisting me in the fieldwork all along. Their company made long journeys on Nigeria’s highways much more fun. I will never forget the discussions we had on Nigeria’s many woes and how to solve them, whether it be on the road; waiting in the car for some lost enumerator; in the Katsina army barracks; or at JBM Guest Inn. Georges’ uncertain proclamations on Nigeria (‘Nigeria hail thou’) will stay with me forever. In other circumstances, Zachs might have chosen a career as a stand-up comedian, since he is gifted with making farmers laugh within minutes of his arrival in a village. This quality made doing research with Zachs not only a wonderful experience, but at the same time made farmers share information willingly.

The distraction some of you provided by visiting us in Nigeria has been of great help, not only in putting my work and PhD worries aside, but also in getting more to grips with the complexities and diversity of Nigeria. Thanks mum and dad for the trips we made to Nguru and Yankari, Sjef and Marijke for the trip to Kaduna State; Mark and Jasmijn for visiting Niger and unmasking the BBC-invented food crises; and Freek and Martijn for our wonderful but so elusive quest for Lake Tchad. Thanks Hannah, Joost, Esther, Julius, Lonneke and Willem for making our holidays in The Netherlands so enjoyable. And thank you all, family and friends, for the understanding you exhibited during the past years.

If it wasn’t for my parents I may have never started a PhD, neither would I have been so interested in problems of development. I you hadn’t offered me the opportunity to travel to Africa for the first time in 1997, which instantly led me to fall in love with the continent, I may have never opted for a career in development. Moreover, you as well stimulated me in combining my position with IITA with a PhD, something which turned out to be working great.

Finally, Marloes never got tired of my frequent requests to check one or two things in a formula, calculation or piece of writing. Naturally, both writing a PhD at the same time creates a mutual understanding and a form of reciprocity, or altruism, or both. Well, at least some form of social capital, which, furthermore, did not depreciate. Without your help, understanding and willingness to join me to Nigeria for such a long time, this thesis would not have been.

Thank you all.

Annex to statement
Name: Ezra Berkhout
PhD student, Mansholt Graduate School of Social Sciences (MG3S)
Completed Training and Supervision Plan

Description	Institute / Department	Year	ECTS*
Courses:			
I. General part			
Writing Grant Proposals	Wageningen Graduate Schools (WGS)	2008	2
Scientific writing	WGS	2009	1.8
II. Mansholt-specific part			
Mansholt Introduction course	MG3S	2007	1.5
III. Discipline-specific part			
Multi-Criteria Decision Making in Agriculture	MG3S	2005	4
Multi-Agent Systems for Natural Resources Management	MG3S	2006	2
Summer school efficiency and productivity analysis	MG3S	2006	3
Advanced Econometrics	MG3S /AEP 50806	2008	6
Development Economics	NAKE	2008	3
IV. Teaching and supervising activities			4
Daily supervision of 2 research associates/technicians IITA	IITA: Kano, Nigeria	December 2004 - December 2007	
Daily supervision 1 student in IITA	IITA: Kano, Nigeria	2006-2007	
Providing assistance in course: Land Degradation and Economic Development	DEC - 21306	March 2008, March 2009	
Providing assistance in course: Methods, Techniques and data analysis for field research	RDS - 21306	May 2008, May 2009	
Presentations (3):			
Mansholt Multidisciplinary Seminar	MG3S	December 2008	1
Presentation at conference of the Center for the study of African Economies	Oxford, United Kingdom	March 2009	1
Two seminars at IITA research stations on bio-economic models, based on chapter in thesis	Kano, Nigeria; Cotonou, Benin	December 2006, February 2007	1
Total (minimum 30 ECTS)			30.3

*One ECTS on average is equivalent to 28 hours of course work

Curriculum Vitae

The author was born on July 29th, 1979 in Wageningen, The Netherlands. After completing secondary school in Wageningen, he studied Econometrics and Operations Research, with a specialisation in Operations Research and Management, at the University of Amsterdam (UvA). Based on his interest in economic development and environment, he carried out research on water use efficiency and agricultural production in Burkina Faso for his Master thesis. Based on this thesis he received his MSc. in 2003.

In 2004 he worked as a junior consultant with Ortec Consultants in Gouda, The Netherlands. Here, he assisted in implementing a software package that optimises vehicle scheduling for various customers in the field of logistics.

At the end of 2004, the author returned to Africa, when he joined the office of the International Institute of Tropical Agriculture (IITA) in Kano (Nigeria) as an Associate Professional Officer. With IITA the author worked in the Cereals and Legumes research program, an interdisciplinary research program comprising social and biophysical scientists with the aim of developing sustainable agricultural technologies for the West African savannah region. Besides working on ad-hoc requests for ex-ante and ex-post impact studies, this position enabled the author to follow a PhD-program based on his research activities with IITA.

To complete his PhD, the author joined the Development Economics Group at Wageningen University in January 2008, where he is currently carrying out research on rice production systems.