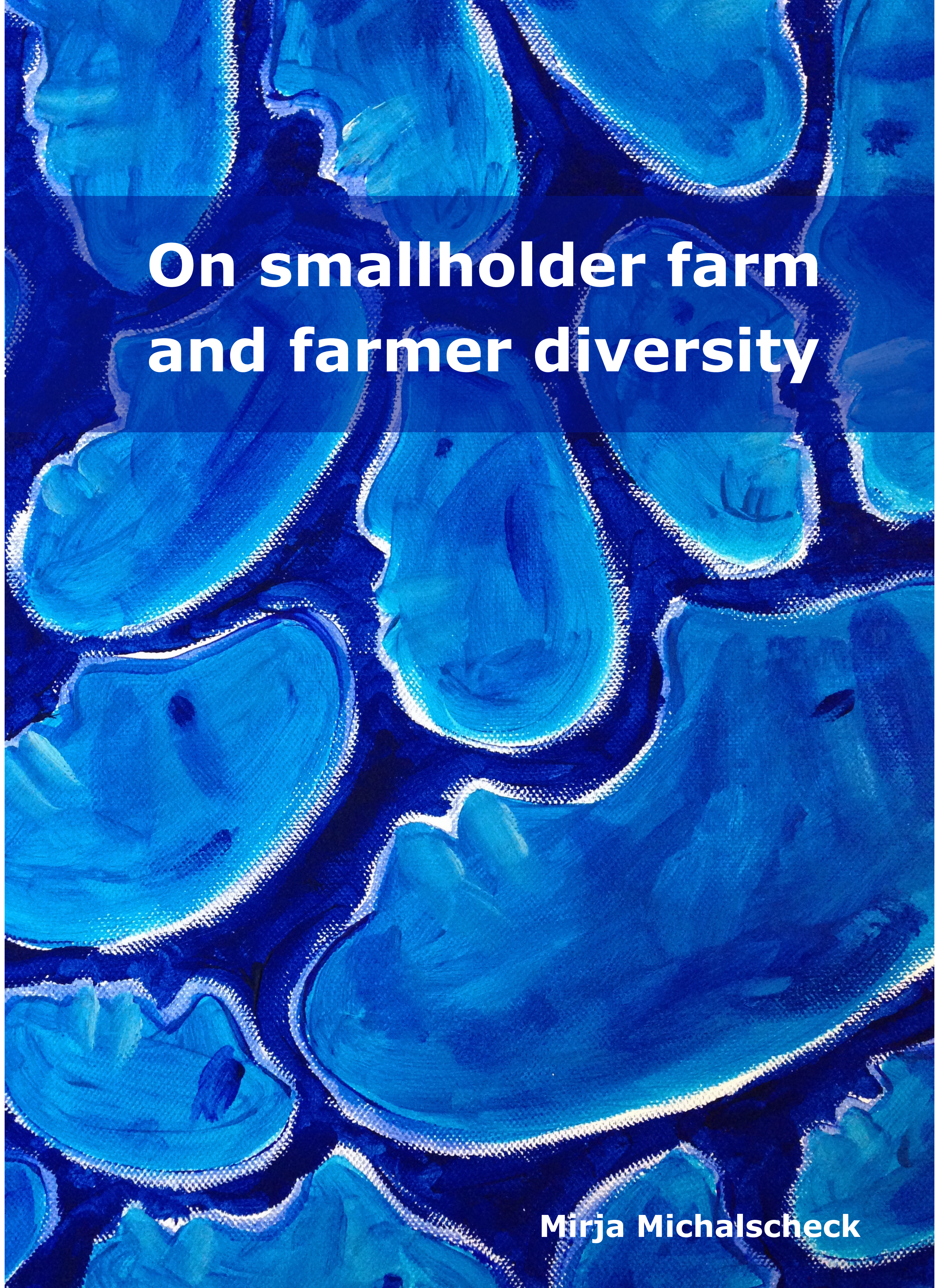
On smallholder farm and farmer diversity

M. Michalscheck

2019



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Propositions

1. Hidden trades are the power of the seemingly powerless.
2. Non-adoption of an agricultural innovation may be the best choice for a farmer.
3. Policies and regulations can be seen as social push-pull systems.
4. Participatory approaches in research for development should express that we participate in people's lives rather than people participating in our research.
5. To predict the success or failure of development projects, a typology of development agents is likely more revelatory than a farm or farmer typology.
6. We do not feed the world by identifying potential solutions in laboratories.
7. Introverts need more habitats on campus.
8. While our merit derives from our human-doing, our value derives from our human-being.

Propositions belonging to the thesis, entitled

On smallholder farm and farmer diversity

Mirja Michalscheck
Wageningen, 6th of March 2019

On smallholder farm and farmer diversity

Mirja Michalscheck

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On smallholder farm and farmer diversity

Mirja Michalscheck

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List of abbreviations

AA	Actual Area
Africa RISING	Africa Research in Sustainable Intensification
CA	Cluster Analysis
GARBES	Ghana Africa RISING Baseline Evaluation Survey
GHS	Ghanaian Cedi
HHH	Household Head
HRE	High Resource Endowed (farm or farmer)
IITA	International Institute of Tropical Agriculture
ISFM	Integrated Soil Fertility Management
LRE	Low Resource Endowed (farm or farmer)
MoFA	Ministry of Food and Agriculture (Ghana)
MRE	Medium Resource Endowed (farm or farmer)
NPK	Nitrogen – Phosphorus – Potassium (fertilizer)
NR	Northern Region (of Ghana)
NRM	Natural Resource Management
P1-P5	(Technology) Package 1 – Package 5
PA	Predicted Area
PC	Principle Component

PCA	Principle Component Analysis
PWU	Power-Weighted Utility
R4D	Research for Development
RE	Resource Endowment
RQ	Research Question
SA	Sulphate of Ammonia (fertilizer)
SOM	Soil Organic Matter
SRC	Severely Resource Constrained
TLU	Tropical Livestock Unit
TSP	Triple Super Phosphate (fertilizer)
UER	Upper East Region (of Ghana)
USAID	United States Agency for International Development
UWR	Upper West Region (of Ghana)

Summary

Feeding the world sustainably is one of today's greatest challenges. The urgency to produce more food from a dwindling resource base calls for a sustainable intensification of agricultural production. Globally, 83% of all farm systems are smallholder farms, whose productivity could increase through the adoption of improved agricultural technologies and techniques. However, smallholders are diverse in their features, constraints and opportunities and so are their possible pathways for sustainable intensification. These pathways are made up of sequential decisions for change. Decisions in smallholder farm systems, *e.g.* on land and labour allocation, are often a matter of negotiation since resources are shared at household level. Therefore, when aiming to understand, anticipate or evaluate resource allocation decisions of smallholders, information is needed on individual interests and household-level decision-making dynamics. In this thesis, I address the question of how inter- and intra-household differences in Northern Ghana shape smallholder farm decisions. Chapter 1 outlines the problem statement, the specific research questions as well as the research context.

In Chapter 2, I characterize local farm systems diversity to determine farm type specific constraints and opportunities for agricultural innovation. I do so, by using the multivariate statistical techniques of principle component analysis and cluster analysis using farm household data (n=80). I determined six farm types, stratified according to household, labour, land use, livestock and income variables: two types of high resource endowment (HRE), two types of medium resource endowment (MRE) and two types of low resource endowment (LRE). The HRE types were oriented towards non-farm activities or crop sales, the MRE types derived their income mainly from on-farm activities and the LRE types were generally oriented towards subsistence. Each farm type was associated to different constraints and opportunities, ranging from composting and better post-harvest storage (LRE), the procurement of

donkeys for transportation and tillage (MRE) to better cattle manure management and crop diversification (HRE).

Chapter 3 compares the etic, statistical typology of Chapter 2 to an emic, participatory typology. The latter resulted into a classification of farmers rather than farms *i.e.* grouping household or community member types (household heads, wives, sons, landless) rather than entire households. The joint application of statistical and participatory approaches provided different but complementary perspectives, allowing a multi-dimensional analysis of farm and farmer diversity.

Chapter 4 operationalizes the insights into the local horizontal (farm) and vertical (farmer) diversity for a nuanced impact assessment of five project-proposed technology packages. I assessed the performance of the technology packages per farm type (LRE, MRE and HRE) and per region (Northern Region, Upper East Region and Upper West Region of Ghana). For the performance assessment I used the whole-farm model FarmDESIGN as well as a weighted scoring technique to systematically capture farmer evaluations. I then compared model results with farmer realities and found that women were more positive about the packages than men, since men heavily penalized extra costs and labour, translating into a greater congruence of model results with the male evaluation. LRE farms were projected to benefit most in relative and least in absolute terms from an adoption of the packages. I also explored alternative farm designs and found that the most promising configurations were hard to attain due to high cost and labour requirements for their implementation. Based on the encountered intra-household differences during the technology evaluation, I decided to take a deeper look at decision-making dynamics in local farm households.

Chapter 5 hence examines intra-household dynamics and trade-offs in land allocation decisions of smallholder farmers, by applying concepts of economics, socio-psychology and physics. I revealed conflicting interests and a mismatch between 'ascribed power' and 'exerted power' suggesting that social power may be deployed, overruled or withheld. Power may be

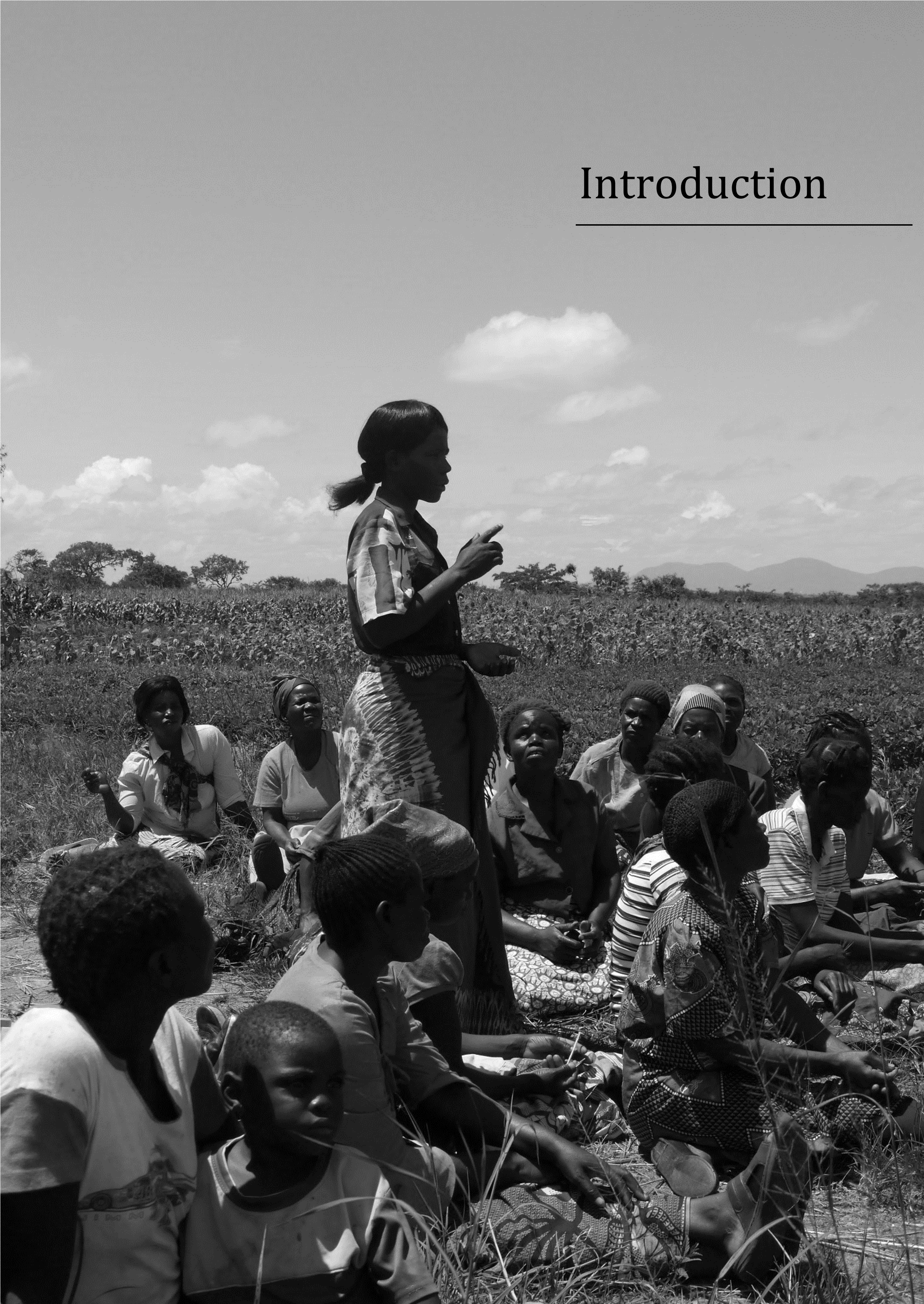
withheld if investments and risks, associated with a negotiation, outweigh the expected utility. Individual and household-level utilities furthermore exposed the social unacceptability of many technically promising land allocation options. I conclude that technical options should be evaluated ex-ante for their likelihood of acceptance and social implications to ensure their basic viability and sustainability.

In Chapter 6, I report on methods and findings of a serious game that simulated an actual household-level negotiation between the male household head, a wife and the eldest son of a hypothetical local farm household. I used social network analysis to quantify interactions during the negotiation. While the household head was the key decision maker acting as a strategic gatekeeper in a funnel-like process, the wife and the son also had a significant influence on the household-level negotiation outcome. Model-based analysis showed that the household-level outcome was more profitable as well as agro-biologically and nutritionally more diverse and productive as compared to the household heads' suggestion. In line with my hypothesis in Chapter 5, power was observed to be actively deployed, withheld or passively overruled depending on the decision domain and process dynamics. I observed an integrative negotiation style, resulting into high levels of satisfaction with the negotiation process and outcome by all parties, who unanimously reported a high level of similarity between simulated and real-life negotiations.

Chapter 7 briefly responds to each research question and elaborates on the comprehensive insights of this thesis, including overall lessons learnt on intra-household decision-making dynamics and a matrix of local farm and farmer characteristics. I discuss the transferability of my methods and findings as well as their contribution to the debate on women empowerment in agriculture. I furthermore reflect on agricultural systems research at the interface between linear and complex systems thinking. I conclude that, in order to effectively support local smallholder farmers, R4D projects are well advised to assess possibly competing interests around any proposed change. Pathways for sustainable intensification are made up of sequential decisions for change, spanning over different decision domains that are administered by different household or community members. A systematic overview of local farm and farmer characteristics as well as participatory inquiries help to understand possible decision-making dynamics, providing a solid basis to formulate or adjust a projects' theory of change and theory of scaling. Finally, it will be the sum of local changes and their synergetic effects that will add up to the global change that is required to sustainably feed the world.

For a short video impression of my work, please scan the QR-code below.

Introduction



1. General introduction

1.1. Global problem statement

Feeding the world sustainably is one of today's greatest challenges (Cui et al., 2018; FAO, 2015). While, by some estimates, global crop demand is projected to double between 2005 and 2050 (Tilman et al., 2011), climate change reinforces uncertainties in agricultural production (IPCC, 2014) and global farm lands are diminishing or degrading (Abass et al., 2018; Bren d'Amour et al., 2017; Lambin and Meyfroidt, 2011; Montanarella et al., 2016). The urgency to produce more food from a dwindling resource base calls for a sustainable intensification of agricultural production, with more productive yet more sustainable farm systems (DeFries and Rosenzweig, 2010; FAO, 2011; Tilman et al., 2011).

Globally, 83% of all farm systems are smallholder farms (Herrero et al., 2017), producing a significant proportion of the food consumed in Africa and Asia (Lowder et al., 2016; UNEP, 2013), supplying the bulk of rural labour (Collier and Dercon, 2009; FAO, 2004) and typically maintaining a high regional agro-biological diversity (Kull et al., 2013; Zimmerer, 2014). Smallholder farms are typically labour intensive production systems, with higher productivity than larger farms (Paul and wa Gĩthĩnji, 2017; Ricciardi et al., 2018) but lower yields compared to their own production potential (Berre et al., 2017; GYGA, 2016; Zhang et al., 2016). Their productivity could be increased by the adoption of improved agricultural technologies and techniques (Harvey et al., 2014; Kunzekweguta et al., 2017; Larson et al., 2016; Mwangi and Kariuki, 2015; Yigezu et al., 2018), with technologies referring to technical changes (*e.g.* inputs, tools, machinery) and techniques to management changes (*e.g.* row planting, crop spacing, sowing date). However, not every technology and technique is suitable for every smallholder farm or farmer. Smallholders are diverse due to their entrenchment in different agro-ecological, socio-cultural and politico-economic environments (Henderson et al., 2016). Even within the same environment, such as an individual farm community or a household, the interests and abilities of smallholders for technology adoption are likely to differ, based on divergent levels of resource endowment, knowledge, skills and risk aversion (Cortez-Arriola et al., 2015; Falconnier et al., 2015; Hammond et al., 2017; Paresys et al., 2018; Tittonell et al., 2010).

Since smallholders are diverse in their features, constraints and opportunities, so are their possible pathways for sustainable intensification (Berkhout, 2009; Tittonell, 2014; ICRISAT, 2015). These pathways are made up of sequential decisions for change. Decisions in smallholder farm systems are often a matter of negotiation since resources are shared at household- or higher institutional levels. Examples for higher institutional arrangements are water user associations, where farmers jointly decide on the supply time and amount of irrigation water (Jha, 2004; Panta and Resurrección, 2014), as well as community managed forests, with community members regulating the access and use of forest space and products (MSTE, 2014; Speelman et al., 2014). By contrast, the allocation of private productive resources depends on intra-household contributions and negotiations, *i.e.* farm activities rely on the concerted financial and labour contributions of various household members (Haddad et al., 1997; Upton, 1987). Household members may, for instance, bargain about the allocation of agricultural inputs (labour, seeds and manure) and farm land (quality and quantity) as well as the distribution of benefits like food and income from sales. Decision-outcomes then depend on the approval, ambition and abilities of influential household members, likely affecting all other household members in the process (Agarwal, 1997; Doss, 2001). Therefore, when aiming to understand, predict or evaluate decisions of smallholders, information is needed on the individual preferences, costs and benefits as well as intra-household decision-making dynamics.

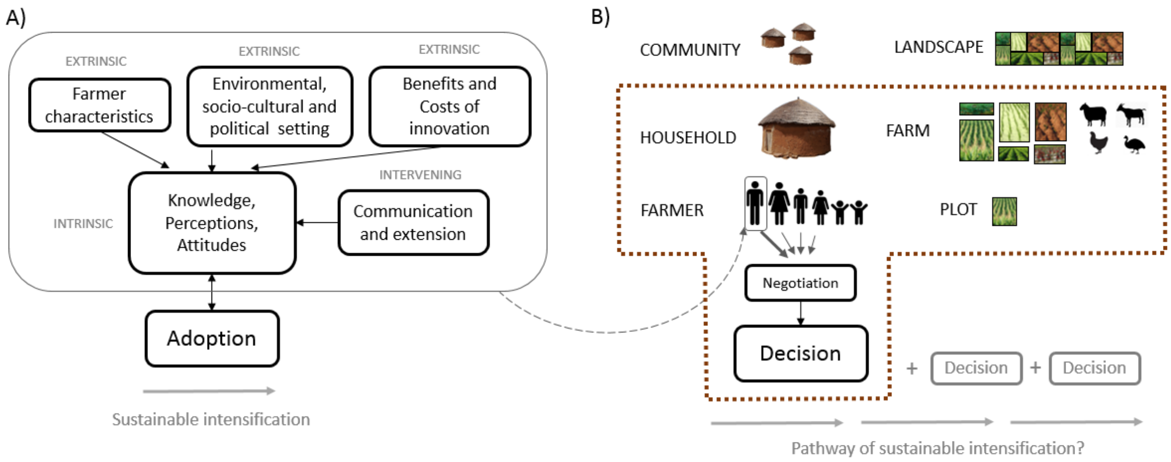


Figure 1.1. *Conceptual frameworks of decision-making processes by smallholders. 1.1A is a simplified framework based on Meijer et al. (2015), showing the linkages and interactions between extrinsic, intrinsic and intervening variables in the adoption of an agricultural innovation by a sole decision maker. 1.1B illustrates natural resource management (NRM) scales, with farms being jointly managed at household-level while specific plots or animals may be under individual (farmer) management. The dotted brown line delineates those parts of the social-ecological system in focus of this thesis.*

However, current technology adoption studies do not reflect the social complexity that shapes decisions in smallholder farm systems: while many studies differentiate between farm-household types (Cortez-Arriola et al., 2015; Ngombe et al., 2014; Singh et al., 2016; Tittonell et al., 2010), they do not differentiate between farmers (individual members) within a household. Despite unitarity being challenged for decades (Folbre, 1984; Haddad et al., 1997; Haider et al., 2018; Jones, 1983), the majority of adoption studies still treat farm households as if there was a sole, representative decision maker (Bensch et al., 2015; Tsiboe et al., 2016), referring to 'farmers and their farms' without specifying who, within a farm household, chose or was chosen to represent it (Dolinska and d'Aquino, 2016; Grace et al., 2015; Karlan et al., 2014; Miassi and Dossa, 2018; Ntshangase et al., 2018; Waithaka et al., 2006; Yigezu et al., 2018). At most, adoption studies consider gender differences between (unrelated) male and female farmers (Bugri, 2008; Duncan, 2004; Emmanuel et al., 2016a; Jarawura, 2014; Khatri-Chhetri et al., 2017; Tetteh Anang, 2015). Figure 1.1A, based on Meijer et al. (2015), illustrates how the adoption of an agricultural innovation is perceived as depending on a sole decision maker.

While studies that consider the adoption-propensity of individual household members miss the subsequent household dynamics, studies that focus on adoption by 'households' miss the underlying interplay of individual interests and power positions as well as intra-household trade-offs. The term intra-household trade-off expresses an impairment of interests of at least one household member resulting from a decision taken to the benefit of at least one other household member. Hitherto, research has mostly assessed trade-offs at farm or landscape-level *e.g.* between farm profitability, ecosystem services, total labour inputs or dietary diversity (Beuchelt et al., 2015; Kanter et al., 2018; Manners and Varela-Ortega, 2018; Takahashi et al., 2018). The assessment of intra-household trade-offs is an important addition to current explorations of alternative farm configurations. Explorations of alternative farm configurations are an attempt to envision concrete, desirable futures of a farm system, facilitating discussions between researchers and farmers on 'how to get there'. With the aim to assist farmers in envisioning options for sustainable intensification, research for development (R4D) projects have proposed a wide range of alternative farm configurations (Kaim et al., 2018; Law et al., 2015; Le Gal et al., 2011), implying changes in land allocation, crop production, agricultural inputs and labour requirements. Suggestions of alternative farm configurations likely imply more comprehensive whole-farm changes than a shift in individual technologies or techniques. In both, studies on individual changes or on alternative farm configurations, there seems to be a knowledge gap on how decisions come about and what they mean to whom within a farm household. This knowledge is particularly relevant for ongoing and future projects, aiming to support smallholder farm systems with a high social complexity and a high urgency for sustainable intensification.

In this thesis, I explore the diversity of inter- and intra-household perspectives, diving beneath the social surface of farm households for a nuanced impact assessment of five project-proposed technology packages, to understand how decisions come about and what they mean to whom within a household (Fig. 1.1B). I do so, by taking the example of smallholder farm systems in Northern Ghana.

1.2. Smallholders in Northern Ghana

Farm systems in Northern Ghana are located in the Guinea and Sudan Savannah agro-ecological zones. Both agro-ecologies are characterized by unimodal rainfall regimes with 1000–1200mm and 900–1000mm of rainfall per year, respectively (Friesen, 2002). Average temperatures range from 26 to 30°C (GMET, 2018). Local livelihoods are based on small-scale, mostly rainfed, low input mixed crop-livestock agriculture, with farmers growing cereals (maize, rice, sorghum, millet), tubers (yam, cassava, sweet potato), legumes (groundnut, cowpea, soybean, bambara bean) and vegetables (tomato, okra, chili pepper, green leafy vegetables) (Tambo, 2016; Yiridoe et al., 2006). Depending on their resource endowment, farmers own cattle, donkeys, small ruminants and poultry, with some non-Muslim households also rearing pigs (Yiridoe et al., 2006).

Livestock mortality rates are high (Amankwah et al., 2012). Crop-related challenges include the low and decreasing soil fertility as well as a poor availability and high cost of land preparation services and inputs such as improved seeds and fertilizers (Akudugu et al., 2012; Britwum and Akorsu, 2016; Dogbe et al., 2012). Withal, input investments do not necessarily pay off due to erratic rainfalls, occasionally causing droughts, leading to crop failure (Jarawura, 2014). Furthermore, the recent fall army worm outbreak in 2017 has caused severe damage to a wide range of crops, including maize, sorghum, groundnut, soybean, millet, rice and vegetables (MoFA, 2017), diminishing the local harvests. Fluctuations in market prices imply uncertainties in the profitability of local agricultural production (Amanor-Boadu, 2011; Dogbe et al., 2013; Gonzalez et al., 2016). Insurance and credit availability is poor and governmental support in the form of subsidies often does not reach farmers reliably or timely (Dogbe et al., 2012). The productivity gaps in the main staple crops maize, sorghum and millet are reported to range between 80 to 90% (GYGA, 2016). Many young farm household members emigrate to nearby urban centres or the capital, Accra, for off-farm opportunities, resulting into rural labour shortages and increased labour prices (Britwum and Akorsu, 2016; Tsiboe et al., 2016). Off-farm income, however, also results in the provision of remittances, financially supporting local farm households (Pickbourn, 2011). The resource base and poverty levels, in fact, differ among the three regions of Northern Ghana, with farms in the Upper East Region (UER) and Upper West Region (UWR) being poorer and more remote than those in the Northern Region (NR). Farm and household sizes are smaller in the UER (1.7 hectares (ha) sustaining 5.8 people (p)) than in the UWR (2.7 ha; 6.2 p) and in the NR (4.9 ha; 7.7 p)(GARBES, 2014; GSS, 2010). Although the outmigration for off-farm labour partially alleviates the rural population pressure, fertile farm land is becoming increasingly scarce, particularly in exurban fringes (Abass et al., 2018; Abubakari et al., 2016). Due to the increasing land scarcity, effective land management and allocation becomes more and more decisive for sustaining local livelihoods.

Local livelihoods and natural resource management (NRM) are strongly shaped by the social set-up of local farm households in Northern Ghana. Households are arranged in so called compounds, hosting nuclear or extended family members of the, typically male, compound head (Al-Hassan and Poulton, 2009; Oppong, 1967). At landscape level, villages and agricultural activities are arranged in a concentric manner with fertile compound fields at the core, surrounded by a patchy arrangement of medium distant fields and an outer circle of remote bush fields (Benneh, 1973; Yiridoe et al., 2006).

Across ethnicities in the Northern Region, agricultural tasks are highly gender differentiated (Doss, 2002): while men are generally responsible for the household's food security through cereal and tuber cultivation, women are expected to provide the soup ingredients such as legumes (cowpea, soybean) and vegetables (Apusigah, 2009; Padmanabhan, 2007). If enough land is available, the younger generation cultivates their own plots, growing sole cash crops like rice to save capital for higher education or marriage. Livestock ownership and responsibilities differ according to gender, too (Doss, 2002). The different crop production objectives might, however, not be one-to-one reflected in farm land allocation to the different crops, since land is largely owned by the typically male household head (HHH). Men own and control communal land, since they inherit the land and only men are allowed to perform land clearing rites and rituals, due to local beliefs about the sanctity of land (Apusigah, 2009; Britwum and Akorsu, 2016; Duncan, 2004). Since, upon marriage, women move from their natal homesteads into their husbands households, they have no entitlement to lands of their natal lineage (Britwum and Akorsu, 2016; Mohammed, 2016). Women's access to land depends on the local inheritance system, land availability, the conception of women's agricultural productivity as well as their recognition as 'farmers in their own right' (Britwum and Akorsu, 2016). Adult members of a male headed household may, however, ask the HHH for the annual use right of a piece of land (Britwum and Akorsu, 2016; Tsikata, 2009). Female household heads do own land, but due to their typically low resource endowment they are reported to have less access to inputs and to be particularly vulnerable to climate change (Tambo, 2016). Female headed households are most prevalent (31%) in the UER, followed by the UWR (19%) and the NR (15%) (GSS, 2010).

The high social complexity and high urgency for sustainable intensification make smallholders in Northern Ghana a challenging but interesting case for investigating farm and farmer diversity as well as local NRM decision-making dynamics.

1.3. Research questions

In this thesis, I address the question of how inter- and intra-household differences in Northern Ghana shape smallholder farm decisions. To systematically answer the main research question (RQ), I address the following specific questions:

RQ1) What farm and farmer types exist in Northern Ghana?
with the objective to systematically explore smallholder diversity.

RQ2) What technology packages work for whom?
with the objective to make a nuanced statement about the suitability of five project-proposed technology packages per farm and farmer type.

RQ3) How do farm-level decisions come about?
with the objective to describe intra-household dynamics and trade-offs in land allocation decisions.

RQ4) How does an actual negotiation look?
with the objective to identify patterns and modes in the interplay of interests and power positions, complementing the insights on RQ3.

1.4. Thesis outline and methods

Each specific RQ is addressed in one or two separate thesis chapters, whose sequence and methods are outlined here:

Chapters 2 and 3 address RQ1, exploring the farm and farmer diversity in Northern Ghana. Chapter 2 employed a principle component and a cluster analysis, *i.e.* multivariate statistical approaches, to group farm households in the Northern Region. Since the statistical approach relied on standardized household-data and etic expert knowledge, we asked farmers how they themselves perceived diversity, leading to a participatory typology. The participatory typology construction was inspired by the Participatory Learning and Action Approach of Pretty et al. (1995). The results of the participatory typology are presented and compared with the statistical typology in Chapter 3, concluding that both, inter- and intra-household diversity matter when trying to understand how farm decisions are made.

Chapter 4 builds upon the insights on local inter- and intra-household diversity to address RQ2. The whole-farm model FarmDESIGN was used to assess the performance of five project-proposed technology packages at household level for one representative farm per type and per region (NR, UER, and UWR). Different members of the representative households then assigned weighted scores to each package, allowing a comparison of model results with farmer realities. While Chapter 4 examines the different interests of the different household members (*e.g.* the HHH, the wife and the son), a decision on the allocation of fundamental productive resources, such as farm land, likely depends on the different power positions, too, *i.e.* on the ability of the different members to assert their interests.

Chapter 5 hence fully dives beneath the social surface of local farm households to identify differences in intra-household interests and power positions, addressing RQ3. Interests and power were assessed through a stick-score method, where ten sticks visualized full satisfaction or complete power and no sticks no satisfaction or no power. The isolated intra-household perspectives were triangulated, combined and deployed in a (power-weighted) utility model as well as in a mathematical vector model, testing whether or not the actual household-level decision-outcome may be predicted. Some contradictions were found between reported and exerted power shares, so I concluded that actual observation of a negotiation process was needed to witness the interplay between interests and power positions.

Chapter 6 addresses this gap as well as RQ4, using a serious game to enable the observation of an actual negotiation process. The game allowed the identification of patterns and modes in the interplay of interests and power positions, corroborating the need for participatory and gender transformative approaches in R4D.

Chapter 7 briefly responds to each RQ and elaborates on the comprehensive insights of this thesis, *i.a.* presenting a matrix of local farm and farmer characteristics. I furthermore discuss the transferability of my findings and their contribution to the debate on women empowerment in agriculture. Last but not least, I reflect on my work at the interface between linear and complex systems thinking before drawing final and actionable conclusions for ongoing and future R4D projects like Africa RISING.

1.5. Africa RISING: research context

This thesis work has been embedded in the R4D project Africa RISING (Research in Sustainable Intensification for the Next Generation, https://africa-rising.net/). The project's definition of sustainable intensification has evolved over time, from aiming at an improved integration of productivity with environmental objectives (IITA, 2012; Pretty et al., 2011) towards the inclusion of socio-economic aspects (IFPRI et al., 2016; Loos et al., 2014; Snapp et al., 2018). Africa RISING has, so far (2012-2017), trained about 52 000 smallholder farmers in Mali, Ghana, Tanzania, Malawi, Zambia and Ethiopia in technologies and techniques for sustainable intensification. Until 2021, Africa RISING aims to reach more than 1 million smallholders, with the vision to 'create opportunities for smallholder households (...) to move out of poverty'. Indicators to measure sustainable intensification are collected at plot-, farm-household- or landscape-level, pertaining to five domains namely the productivity, economic, environment, human condition and social domain (Musumba et al., 2017). Trials and surveys are conducted with male and female farmers of different age groups and data may be gender-disaggregated but does not systematically reveal differences within particular households.

This thesis contextualizes and deepens the R4D work by Africa RISING (Fig. 1.2), starting with a farm and farmer typology at the regional level (RQ1: Chapters 2 and 3), proceeding with an assessment of project-proposed technology packages at household level (RQ2: Chapter 4) and, finally, diving beneath the surface of local farm households to better understand underlying intra-household decision-making dynamics (RQs 3 and 4: Chapters 5 and 6).

I commenced my work with Africa RISING in Ghana in 2015, when the first two years of farmer-led trials had just been completed, allowing a first agronomical evaluation of the different project-proposed 'technology packages'. The project had identified a 'basket of technologies' *i.e.* a number of promising technologies and techniques, so that the mere question that remained seemed to be who would adopt them ('solutions - for whom?') and what were the constraints to adoption. I realized that R4D activities may be seen as operating along a three-step process (Fig. 1.3), originating from the identification of (1) 'a problem', followed by the determination of (2) a corresponding 'solution' and, finally, (3) the adoption of the solution by the farmer. When wondering about the low technology adoption among smallholder farmers, one needs to ask whether 'a solution' indeed addresses the farmers' most pressing problems, whether it is technically and socially viable, not creating new problems and whether an adoption is possible at all: is the technology accessible? Is it affordable? Does the farmer have the skills to make use of it? In order to contextualize my thesis research on the project-proposed 'solutions' I started investigating whether the farmers' and Africa RISING's definition of 'problems' and 'solutions' matched: Africa RISING,

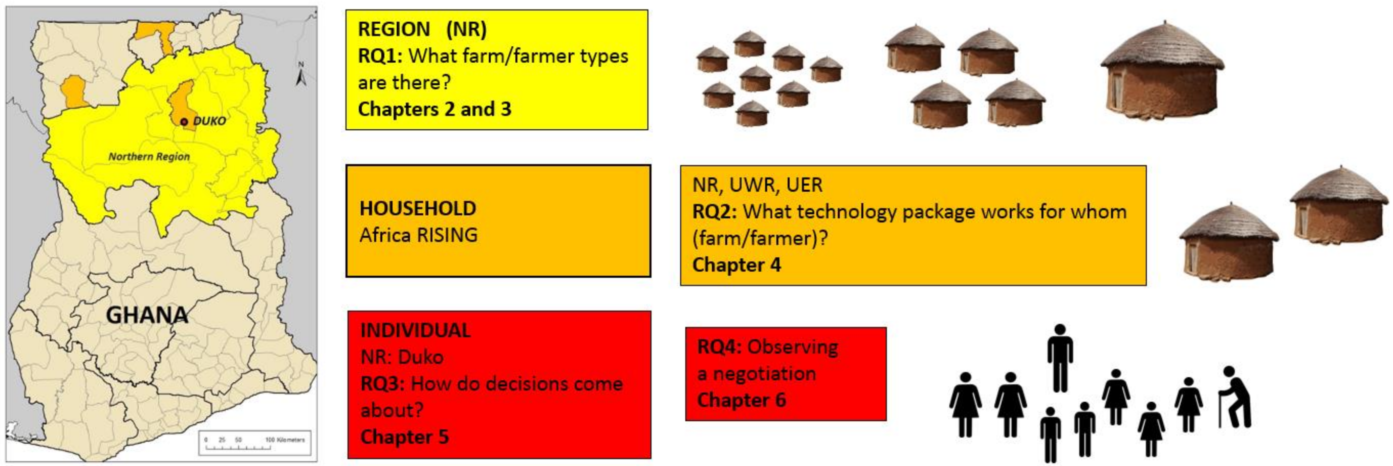


Figure 1.2. *Scales of thesis research, contextualizing and deepening the R4D work of Africa RISING*

in fact, had built their technology packages based on 47 participative community analyses in the NR, UER and UWR (Ellis-Jones et al., 2012). Two years after the start of project activities, the Ghana Africa RISING Baseline Evaluation Survey (GARBES, 2014) data (N=1284) confirmed that farmers considered the project-proposed technology packages as relevant and attractive (*cf*. Annex 1A). Farmers reasons for non-participation (n=233) were mainly related to insufficient information (57%), insufficient time (15%) or to being 'turned down' by the project (12%). Along the lines of the three-step R4D-process, I conducted a short survey in Duko (NR) and Nyangua (UER), asking farmers (N=89, age: 24-60 years) what, for them, were the most pressing problems (0=no, 1=low, 2=medium, 3=high importance (I)) in agricultural production, whether they were aware of any solutions and whether or not Africa RISING was supporting them with these solutions. I also asked whether farmers were implementing the solutions and if not, why.

In summary, high input costs, input unavailability as well as low soil fertility were the main challenges reported by farmers (*cf*. Annex 1B), matching well with the 'action domains' of the project-proposed technology packages. While in Duko, 72% of the respondents felt supported (on problems of I>1) by Africa RISING, in Nyangua only 33% stated the same, possibly due to the community's greater remoteness. However, the vast majority (95%) of the respondents in both sites indicated to be aware of a solution to problems of medium or high importance and to adopt them (95%). While the problem and solution definitions by farmers and the project appeared to be similar, it seemed as if the project had not effectively or equally reached farmers in Duko and Nyangua. It also seems as if the narrative of a low adoption rate is an external perspective rather than the farmers' point of view. With this thesis, I aim to contribute to a better understanding of local perspectives on farm management and resource allocation decisions given the local smallholder farm and farmer diversity.

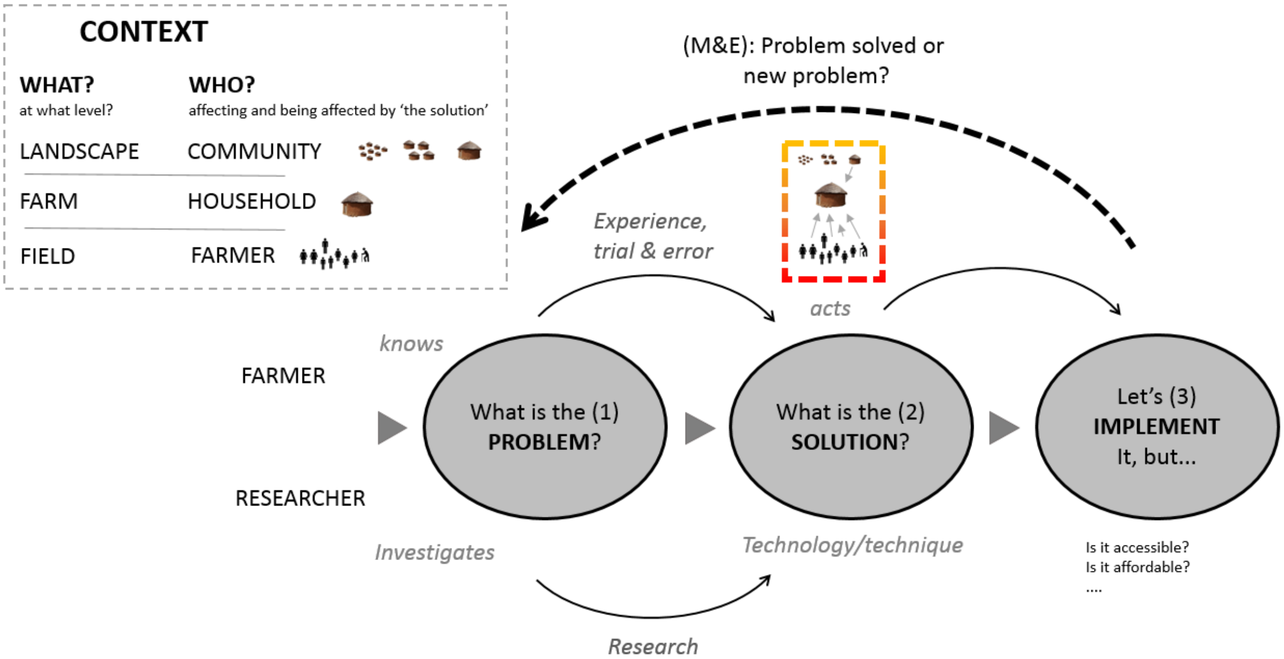


Figure 1.3. *Three-step process contextualizing Research for Development (R4D): (1) Problem, (2) Solution and (3) Adoption. Farmers and researchers might have different perspectives on each step. Farmers are embedded in households and communities, sharing resources, partially dependent in their resource management decisions. The yellow-to-red-frame indicates the topical niche of this thesis.*

Chapter 2

2. Farm diversity

Based on:

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Abstract

Typologies may be used as tools for dealing with farming system heterogeneity. This is achieved by classifying farms into groups that have common characteristics, *i.e.* farm types, which can support the implementation of a more tailored approach to agricultural development. This article explored patterns of farming system diversity through the classification of 70 smallholder farm households in two districts (Savelugu-Nanton and Tolon-Kumbungu) of Ghana's Northern Region. Based on 2013 survey data, the typology was constructed using the multivariate statistical techniques of principal component analysis and cluster analysis. Results proposed six farm types, stratified on the basis of household, labour, land use, livestock and income variables, explaining the structural and functional differences between farming systems. Types 1 and 2 were characterized by relatively high levels of resource endowment and oriented towards non-farm activities and crop sales respectively. Types 3 and 4 were moderately resource endowed with income derived primarily from on-farm activities. Types 5 and 6 were resource constrained, with production oriented towards subsistence. The most salient differences among the farm types concerned herd size (largest for Type 1), degree of legume integration (largest for Types 2-4), household size and hired labour (smallest household size for Types 4 and 6, and largest proportion of hired labour for Type 4), degree of diversification into off/non-farm activities (highest for Type 1 and lowest for Type 5) and the severity of resource constraints (Type 6 was most constrained with a small farm area and herd comprised mainly of poultry). It was found that livelihood strategies reflected the distinctive characteristics of farm households; with poorly-endowed types restricted to a 'survival strategy' and more affluent types free to pursue a 'development strategy'. This study clearly demonstrates that using the established typology as a practical framework allows identification of type-specific farm household opportunities and constraints for the targeting of agricultural interventions and innovations, which will be further analysed in the Research for Development project. I conclude that a more flexible approach to typology construction, for example through the incorporation of farmer perspectives, might provide further context and insight into the causes, consequences and negotiation of farm diversity.

Keywords: diversity; farming systems; Ghana; multivariate analysis; typology

2.1. Introduction

Africa is predominantly rural, with 54% of the population engaged in agriculture (FAO, 2014a). The majority of farmers cultivate small, fragmented parcels of land, yet are responsible for the bulk of food production, making the smallholder farm sector a key player in the continent's rural economy (Chamberlin, 2007; Wiggins, 2009). A farming system is defined as the complex of resources that are arranged and managed according to the totality of production and consumption decisions taken by a farm household, including the choice of crops, livestock, on-farm and off-farm enterprises (Fresco and Westphal, 1988; Giller, 2013; Köbrich et al., 2003). Smallholder farming systems are perceived to share certain characteristics which differentiate them from large-scale, profit-driven enterprises. These include: limited access to land, financial capital and inputs, high levels of vulnerability and low market participation (Chamberlin, 2008, 2007). However, the macro- and micro-level structures, drivers and constraints of these systems are shaped by constant interaction with the local social and biophysical context (Chapoto et al., 2013; Ngeleza et al., 2011; Tittonell et al., 2010). The result is farming system diversity in space (*e.g.* based on resource endowment), variability through time (dynamism) and multidimensionality in terms of strategy (production and consumption decisions) (Mortimore and Adams, 1999). Therefore, not all smallholders are equally land constrained, resource poor or market oriented, and any effort to understand or develop the smallholder sector needs to start with an acknowledgement of this heterogeneity.

A practical way of dealing with farming system complexity and diversity is to artificially stratify smallholders into subsets or groups that are homogenous according to specific criteria *e.g.* have broadly similar resource bases, enterprise patterns, livelihoods and constraints (Köbrich et al., 2003). Farm typologies attempt to perform such groupings; the term 'typology' designating both the science of type delineation and the system of types resulting from this procedure (Landais, 1998). The choice of differentiating criteria depends on the objective of the typology and the kind of data available (Kostrowicki, 1977; McKinney, 1969). Results can then be used to support the development (selection of farms), implementation (targeting and scaling-out of innovations) and monitoring (scaling up of impact assessments) of agricultural development projects (Alvarez et al., 2014; Byerlee et al., 1988; Emtage et al., 2007). In addition to being a practical framework on the basis of which more differentiated approaches to addressing rural challenges may be designed, typologies might also inform the academic study of farming system heterogeneity. For example, they can be applied to assist in-depth farming system analyses or inform further exploratory studies through the selection of representative farms for detailed characterization. Typologies may also be used in modelling and simulation studies to evaluate potential effects of specific interventions on farming systems (Andersen et al., 2007; Köbrich et al., 2003; Landais, 1998).

Several studies have defined farmer classes and livelihood patterns to describe farming systems in different parts of Africa, using a range of criteria which often overlap across regions and agro-ecological zones (*cf*. Chikowo et al. (2014) for a review on smallholder typologies in Sub-Saharan Africa). This article contributes to an existing, but relatively sparse strand of literature on farming system characterization in Ghana. Using survey data collected from seven case-study villages across the country, a seminal study by Benneh (1973) derived a broad classification of the farming systems found within Ghana using the method of soil fertility maintenance and land tenure system as main discriminating criteria. Much later, focusing exclusively on Wenchi district in the Brong-Ahafo region, two qualitative studies explored farm household diversity using migrant versus native status (Adjei-Nsiah et al., 2004) and ethnicity, gender and wealth (Adjei-Nsiah et al., 2007b) as variables. The latter classifications were both based on participatory methods such as wealth ranking. Another study by Ghana's Ministry of Food and Agriculture (MoFA) disaggregated farm households in 16 predominantly northern districts of the country according to their livelihood strategies, using a participatory approach (Al-Hassan and Poulton, 2009). More recently, in 2011, a study commissioned by the International Food Policy Research

Institute examined the spatial disaggregation of crop production and input use patterns across the different agro-ecological zones of Ghana making use of the nation-wide Ghana Living Standards Survey 5 dataset (Quiñones and Diao, 2011). However, to the authors' knowledge, no published studies have characterized Northern Ghanaian farming systems using more formal analytical (statistical) methods.

Adopting an inductive approach, this article explores farming system variability in two districts (Savelugu-Nanton and Tolon-Kumbungu) of Ghana's Northern Region through (*i*) the identification and characterization of farm types, (*ii*) analysis of patterns and inter-relationships between the types and (*iii*) consideration of the implications of findings for more efficient tailoring of agricultural support to farm type-specific challenges. In order to achieve these objectives, a typology was constructed on the basis of recent survey data incorporating multiple, quantitative variables of farm structure (describing resource endowment) and farm functioning (describing livelihood strategies) (Iraizoz et al., 2007; Tittonell, 2014). Farm clustering arose from multivariate analysis of these variables, using the well-known techniques of principal component analysis (PCA) and cluster analysis (CA) (Bidogeza et al., 2009; Chavez et al., 2010; Cortez-Arriola et al., 2015; Köbrich et al., 2003; Tittonell et al., 2010). Key strengths of this approach are its reproducibility, ease of comparison across space and time, and manageability- datasets can be analysed with speed and accuracy (Kostrowicki, 1977).

2.2. Materials and methods

2.2.1. Project, site selection and data sources

The research was embedded in a multi-country Research for Development (R4D) program; Africa Research in Sustainable Intensification for the Next Generation (Africa RISING), supported by the United States Agency for International Development (USAID) as part of the United States government 'Feed the Future' initiative (http://africa-rising.net/). Operating within a time horizon of five years (2012-2016), the program aims to create opportunities for smallholder farm households to escape hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, while conserving or enhancing the natural resource base (IITA, 2012). The project is active in East and Southern Africa (Ethiopia, Tanzania, Malawi and Zambia) and in West Africa (Mali and Ghana). In each site, the challenge is to achieve project goals while paying particular attention to smallholder diversity within and across the rural landscapes. Therefore, identification of farm types in project regions, at the level of selected Africa RISING intervention communities, is an important first step for the program.

Africa RISING in Ghana, led by the International Institute of Tropical Agriculture (IITA), comprises the three most poverty-stricken geographical and administrative regions in the north; namely the Northern Region, Upper East Region, and Upper West Region. In September 2013, 240 farm households were surveyed across these three regions as part of a rapid characterization or baseline study. In each region, about 80 households were randomly selected from Africa RISING intervention communities for interviews using a structured questionnaire. Basic information on household composition and education of household members, land holdings, livestock ownership, labour use, assets, housing, production orientation, major crops and sources of income was collected. This article makes use of the resulting dataset from the Northern Region (*i.e.* Savelugu-Nanton and Tolon-Kumbungu districts) focusing on the classification of these farm households.

2.2.2. Study area

The Northern Region occupies 70 383 km^2 which constitutes over two fifths of the area of modern Ghana, and is divided into 20 districts. The case-study area is located in Savelugu-Nanton and Tolon-Kumbungu districts of the Northern Region, about 30-40 km outside of Tamale (regional capital). Three Africa RISING intervention communities were surveyed, namely; Botingli (9.61° N 0.79° W, Savelugu-Nanton district *n*=21), Kpalung (9.68° N 0.78° W, Savelugu-Nanton district, *n*=28) and Tingoli (9.37° N 1.01° W, Tolon-Kumbungu district, *n*=31) (Fig. 2.1). The region is economically poor with little industry and despite its geographical size; the current population constitutes only about one fifth of the country total (Kelly and Bening, 2007). Vegetation falls into the Guinea-Savannah zone, which is characterized by vast, low-lying areas of semi-arid grassland interspersed with savannah woodland, a dry and hot climate, unimodal rainfall and fragile, sandy-loam soils often overlying impenetrable ironpan or laterite (Ellis-Jones et al., 2012; Wiredu et al., 2010).

The three surveyed communities are inhabited mostly by members of the Dagomba ethnic group, who comprise about a third of the population of the region (Ellis-Jones et al., 2012). The basic unit of social organization among the Dagomba is the farm household, centred around a 'compound' where the head (typically male) lives with his nuclear or extended family (Al-Hassan and Poulton, 2009; Oppong, 1967). Livelihoods are based on small-scale, low-input, mixed crop-livestock agriculture and farmlands tend to follow the typical concentric spatial arrangement found elsewhere in Africa, comprised of nucleated human settlements in the middle, inner rings of fertile compound farms, medium distance fields, and outer rings of more distant bush farms (Yiridoe et al., 2006). Traditionally cultivated according to the bush fallow system, most farms are now under annual or permanent cultivation (Adikwu, 2014; Benneh, 1973). Staple food crops include maize (which doubles as a cash crop), yam and cassava. Rice and legumes such as groundnuts, soybean and cowpea constitute the main cash crops. Yields are generally poor due to low and erratic rainfall, low and declining soil fertility, lack of quality seed and land preparation equipment, high cost of inputs and labour constraints (Timler et al., 2014). Cattle, sheep, goats and poultry are kept as livestock for food, income, wealth accumulation, sacrificial purposes and to a lesser extent for their supply of inputs such as manure (used as organic fertilizer) and draught power (Ellis-Jones et al., 2012; Sansoucy et al., 1995). Productivity of animals is low due to inappropriate feeding and animal husbandry practices that result in high mortality rates. Furthermore, farmers only have limited access to veterinary services and improved livestock breeds. In general, crop and livestock enterprises are weakly integrated (Timler et al., 2014) .

__Figure 2.1.__ Map of the Northern Region of Ghana (inset) showing the location of Africa RISING intervention communities (red points); Kpalung, Botingli and Tingoli, in Savelugu-Nanton and Tolon-Kumbungu districts.

2.2.3 Dataset

The survey dataset for the Northern Region contained information from 80 geo-referenced farm households across three Africa RISING intervention communities (*i.e*. Botingli, Kpalung and Tingoli). Quantitative variables (12) related to the characteristics of the household, labour, land use, livestock and household income, were used to explore the farming system diversity of the case-study area through multivariate analysis (Table 2.1).

***Table 2.1**. Description of variables used for farm typology construction.*

Variable	Unit	Mean	±SEM	Min.	Max.
Household					
Size of household	Number of members	15.2	0.97	4	37
Labour					
Total labour input[a]	Hours per year	2450.5	174.22	256	7048
Hired labour ratio		0.1	0.01	0	0.44
Land use					
Cropped land area[b]	Hectares	3.8	0.24	0.81	9.31
Maize ratio[c]		0.5	0.02	0.19	1
Legume ratio[d]		0.2	0.02	0	0.68
Livestock ownership					
Herd size	TLU[e]	3.2	0.39	0.15	17.31
Small ruminant ratio[f]		0.6	0.04	0	1
Poultry ratio[g]		0.2	0.03	0	1
Income					
Crop sales[h]	Percentage	36	3	0	86
Livestock sales[i]	Percentage	21	2	0	76
Off/non-farm income[j]	Percentage	16	2	0	70

[a]Family, hired- and exchange labour input for crop production (the sum of all reported labour per plot per household); [b]Land used by farmers for crop production (the sum of all reported plot sizes per household); [c]Share of arable land cropped to maize; [d]Share of arable land cropped to legumes: beans, soybeans, groundnuts, cowpeas; [e]Tropical Livestock Unit: livestock conversion factors based on Jahnke et al. (1987); *[f]Share of small ruminants in total TLU (herd): goats and sheep; [g]Share of poultry in total TLU (herd): chickens, ducks, turkeys, pigeons and guinea fowls; [h]Share of crop products sold on the market; [i]Share of livestock products sold on the market; [j]Share of income derived from off/ non-farm activities.*

2.2.4. Typology construction

Two multivariate statistical techniques were employed sequentially for generating a typology of the surveyed farm households: PCA to reduce the dataset into non-correlated components and CA for partitioning the PCA output into clusters. The approach has been used in many studies to categorize farming systems (Bidogeza et al., 2009; Chavez et al., 2010; Cortez-Arriola et al., 2015; Köbrich et al., 2003; Tittonell et al., 2010). All analyses were executed in R (version 3.1.0) with the ade4 package (version 1.6-2, available online at: http://pbil.univ-lyon1.fr/ADE-4/) and the *cluster* package (version 1.15.2).

2.2.4.1. Principal component analysis

To avoid distortions in the statistical analysis, the dataset based on the 12 variables was carefully examined by evaluating missing data and identifying potential outliers. Boxplots were used to detect outliers which were deleted at the risk of improving the multivariate analysis while limiting its generalizability to the entire population (Hair et al., 2010). Of the 80 farm households sampled by the survey, 70 were retained for statistical analysis (*i.e.* 10 farm households were identified as outliers or containing incomplete data).

The decision of how many principal components (PC's) to keep was made based on three criteria: (*i*) according to Kaiser's criterion, all PC's exceeding an eigenvalue of 1.00 were initially retained (Chavez et al., 2010; Köbrich et al., 2003). This decision was cross-checked by looking at (*ii*) the minimum cumulative percentage of variance chosen, here 60% (Table 2.2). The final criterion, that of (*iii*) interpretability, was used to assess the conceptual meaning of the PC's in terms of the apparent constructs under investigation. This was done by examining the correlations between the variables and the PC's (Chessel et al., 2004; Husson et al., 2011); higher correlation coefficients signified a closer relationship to the PC (Lebart et al., 1995)(*cf.* circles of correlation from Fig. 2.2). In this study, loadings greater or equal to 0.50 were considered for interpretation purposes (Iraizoz et al., 2007).

2.2.4.2. Cluster analysis

The PCA output in the form of a reduced dataset based on the retained PC's was subjected to CA. A two-step approach was followed: first, a hierarchical, agglomerative clustering algorithm using Ward's method was employed to define the number of groups (*k*), and then a non-hierarchical, partitioning algorithm (Partitioning Around Medoids) was employed to refine these *k*-groups.

Ward's method resulted in a range of cluster solutions, where each observation started out as its own cluster and was successively joined by similar clusters until only a single cluster remained (Reynolds et al., 2006). This agglomerative nesting process was represented by a dendrogram. In determining the optimal cluster cut-off points, a trade-off was sought between the number of clusters and the level of dissimilarity between clusters, with the objective of maximizing both intra-cluster homogeneity and inter-cluster heterogeneity (Hair et al., 2010).

The number of clusters retained from Ward's method was used as a starting value by the non-hierarchical algorithm, which was performed to improve the robustness of the classification by optimizing farm distribution among clusters so as to minimize the sum of the distances of each observation from its cluster centre (Reynolds et al., 2006; Rousseeuw, 1987). To characterize the final set of clusters, they were examined in terms of their inherent structure (*i.e.* the mean value of each variable for each cluster).

Finally, the farm types were validated by an agricultural expert with an intimate knowledge of the local farming systems (former MoFA extension officer for the Northern Region).

The patterns of the multivariate system, *i.e*. intra-group features and inter-group relationships were analysed, the farm types mapped and the implications of farm type-specific characteristics and strategies for innovation targeting considered.

2.3. Results and discussion

2.3.1. Characterization of farm types

The PCA resulted in the extraction of the first five PC's explaining about 66% of the variability in the dataset (Table 2.2). The first PC explained the greatest part of the variation, about 19.4% of variability in the data.

Table 2.2. *Eigenvalues and percentage variance explained by five principal components (PC's) using PCA.*

PC	Eigenvalue	Variance (%)	Cumulative Variance (%)
1	2.33	19.4	19.4
2	2.05	17.1	36.5
3	1.42	11.8	48.3
4	1.20	10.0	58.3
5	0.97	8.1	66.4

The first component (PC 1) was closely related to the variables describing household size (*sizehh*) and animal resources (total TLU or *tottlu* and small ruminant ratio or *rumratio*), and less closely related to the hired labour ratio (*hiredratio*). Thus, it seemed to explain the human and animal capital of farm households (Fig. 2.2A). The second component (PC 2) correlated highly with land use variables (maize ratio or *maizeratio* and legume ratio or *legratio*) and total annual on-farm labour input (*totlab*). It was more weakly correlated with the cropped land area (*landsize*) (Fig. 2.2A). The third component (PC 3) described herd composition (poultry ratio or *poultryratio*) and management (livestock sales or *livsales*) (Fig. 2.2B). The fourth component (PC 4) was related to off/non-farm activities (*offincome*) (Fig. 2.2C). Finally, the fifth component (PC 5) was represented by the crop sales percentage (*cropsales*), giving insight into the production objective of households (Fig. 2.2D). The results from the hierarchical clustering algorithm suggested a six-cluster cut-off point (Fig. 2.3), and the non-hierarchical algorithm re-assigned farms to the identified clusters. Thus, it emerged that the households of the study area could be grouped into six broad farm types contrasted by their structural (resource endowment[1]) - and functional (production objectives/ livelihood strategies) characteristics (Fig. 2.2E-H and Fig. 2.4):

***Type 1**: Well resource endowed with large cattle herd, maize-based cropping system and ample non-farm activities (11% of the sampled farms)*

Type 1 was dissociated from the others due to the strong discriminating power for variables related to herd size and composition, household size and engagement in non-farm activities (Fig. 2.2). Thus, Type 1 comprised mainly large households (about 22 people) providing the majority of on-farm labour (96%), and the largest animal herds (on average 10 cows, 10 goats and 10 sheep). The cropped area tended to be dedicated to the production of maize (50%). Conversely, the percentages of livestock sales were the lowest among all farm types, while off/non-farm activities contributed to a large portion (about 32%) of the household income (Fig. 2.4).

***Type 2**: Well resource endowed with larger farm areas, legume and maize-based cropping system, market oriented (10% of the sampled farms)*

Type 2 was characterized by the largest farm areas (average of 6.3 ha), with just over a third of the area cropped to maize (one of the lowest maize ratios among types) and another third to legumes (one of the largest legume ratios among types). Type 2 relied heavily on the sale of crop products: more than half of all crop products were sold on the market (Fig. 2.4). It exhibited the second largest animal herds (on average 7 cows, 4 goats and 3 sheep). The relatively large household provided most of the total labour input per year (low hired labour ratio).

[1] This refers to wealth-related variables such as farm size, livestock ownership and household size (Tittonell et al., 2010).

***Type 3**: Medium resource endowed with herd dominated by small ruminants, legume- and maize oriented, on-farm labour intensive (13% of the sampled farms)*

For Type 3, the main distinguishing features included herd composition and total labour input per year (Fig. 2.2). The herd exhibited a relatively small size (2.4 TLU) and consisted mainly (about 80%) of small ruminants (on average no cattle, 9 goats and 9 sheep). Labour hours per year were the highest for this farm type, with a relatively large proportion of hired labour (about 8%). With 5.2 ha on average, this group cultivated the second largest area, of which a third was cropped to maize and a third to legumes (Fig. 2.4).

***Type 4**: Medium resource endowed with herd dominated by small ruminants, ample hired labour and farm income provided mostly by crop product sales (46% of the sampled farms)*

Type 4 was the largest cluster. It is distinguishable from the other types mainly by its larger hired labour ratio counter-balancing its small household size (Fig. 2.4). Total labour input was low for this farm type, especially considering the medium sized land area (about 3.5 ha), but the share of hired labour was the highest at 14%. The cultivated land area, dominated by maize and legumes, provided most household income through crop product sales (almost 50% of all crop products were marketed) (Fig. 2.4). The size of the herd was relatively small (1.9 TLU) and mostly (70%) comprised of small ruminants (about 1 cow, 6 goats and 6 sheep).

***Type 5**: Resource constrained, maize-based cropping system and almost no income generated by off/non-farm activities (14% of the sampled farms)*

Type 5 exhibited the smallest farm areas (about 2.5 ha), mostly dominated by maize (about 74% of the arable land) and the lowest legumes proportion compared to other clusters (only 4%). This cluster also had the lowest share of off/non-farm income (about 8%). Herd size was generally quite small and animal production was centred on small ruminants and poultry (average ownership of 1 cow, 6 goats, 9 sheep and 34 poultry). Total labour hours per year were relatively low (Fig. 2.4).

***Type 6**: Severely resource constrained, with a small herd dominated by poultry, income generated from livestock product sales and off-farm activities (6% of the sampled farms)*

Type 6 was the smallest cluster, characterized by small cropped area (2.6 ha, with about 47% allocated to maize) with the lowest total labour hours per year and smallest herd size (Fig. 2.4). Livestock (about 0.3 TLU) consisted almost entirely of poultry (about 89%). The main income resource was livestock product sales (about 42%), complemented by income from off-farm activities (about 25%). Furthermore, in contrast to similarly land-constrained Type 5, household size was small (Fig. 2.4).

2.3.2 Farming system patterns

Studies have shown that the differentiating characteristics of farming systems are driven by site-specific opportunities and constraints that in turn are shaped by various factors beyond the household scale at the community, landscape, and regional levels (such as agro-ecology, markets, institutions, traditional land tenure and inheritance systems) (Chapoto et al., 2013; Tittonell, 2014; Tittonell et al., 2010; Yaro, 2010a). These differences influence the coping and adaptive strategies of farmers in the face of shocks (volatile prices, crop failure, droughts, unexpected expenditures *etc*.) and stresses (declining soil fertility, climate change, land scarcity *etc*.), as well as their interest and capacity to take advantage of potential opportunities for the sustainable intensification of their farms (Chamberlin, 2007; Yaro, 2010a). In the following sections, the determinants and implications of farming system diversity are discussed in relation to variables (grouped according to theme), their interrelationships and the identified farm types within the context of the case-study area.

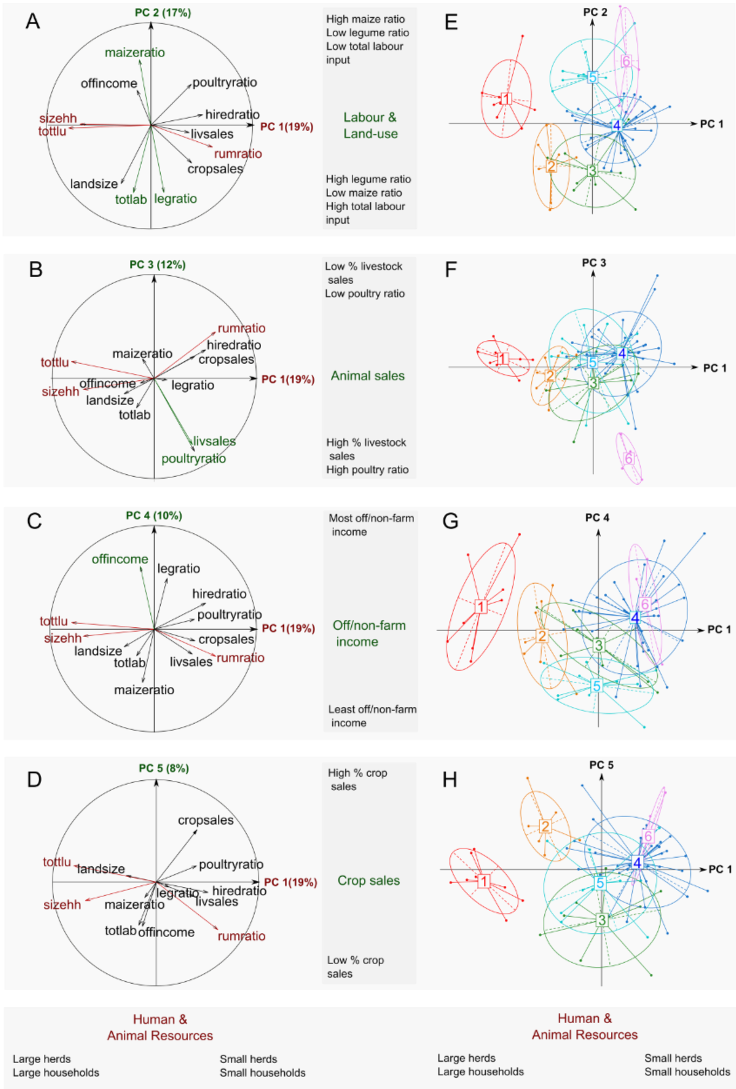


Figure 2.2. *PCA and CA output: circles of correlation (A-D) and clusters i.e. farm types 1-6 (E-H) in the planes PC1-PC2, PC1-PC3, PC1-PC4 and PC1-PC5. The directions and lengths of arrows within the circles show the strength of the correlations between variables, and variables and PC's. The arrows highlighted in red represent those variables that correlate strongly (>0.60) with PC 1, whereas the arrows highlighted in green represent those variables that correlate strongly with each subsequent PC. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).*

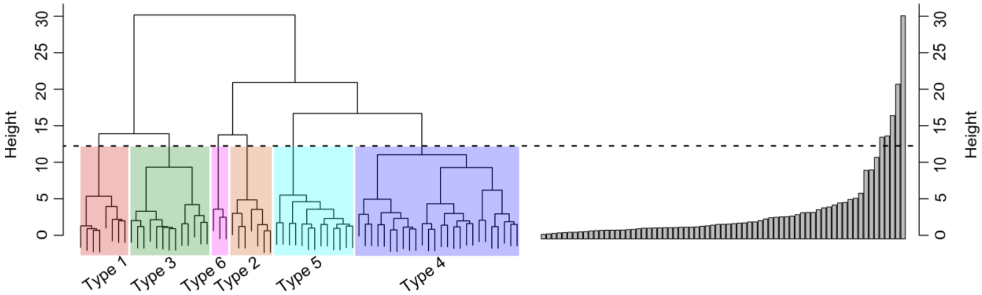


Figure 2.3. *Dendrogram (left) and associated bar plot (right) displaying a range of cluster solutions resulting from Ward's method of CA. The dashed line shows the selected cut-off point which gave the six-cluster solution (Types 1-6). The vertical axis represents the agglomeration coefficient (the 'height' or distance between clusters merged at each stage).*

2.3.2.1 Household

The literature suggests that the size and composition of the domestic group varies according to the rank, occupation, wealth and maturity of its household head (Ngeleza et al., 2011; Oppong, 1967). Our analysis revealed a strong positive correlation between household size and herd size; the latter constituting an important indicator of wealth (Laube, 2007)(Fig. 2.2A). In particular, Type 1 farm households with larger herds that included valuable cattle, tended to exhibit above-average household sizes (Fig. 2.4A and G). Interestingly, Type 1 households were also headed by the oldest men (*cf.* Annex 2).

2.3.2.2 Land use

Among the patrilineal Dagomba, land is inherited by the household head and typically fragmented into smaller parcels that are allocated to household members (Ohene-Yankyera, 2004; Oppong, 1967). Other less common access routes to land include purchase and borrowing (Yaro, 2010b). Results revealed differences in mean farm size across types, with Type 2 exhibiting the largest cropped land areas on average (Fig. 2.4D). Interestingly, Type 2 farmers were not surveyed in Botingli, the smallest

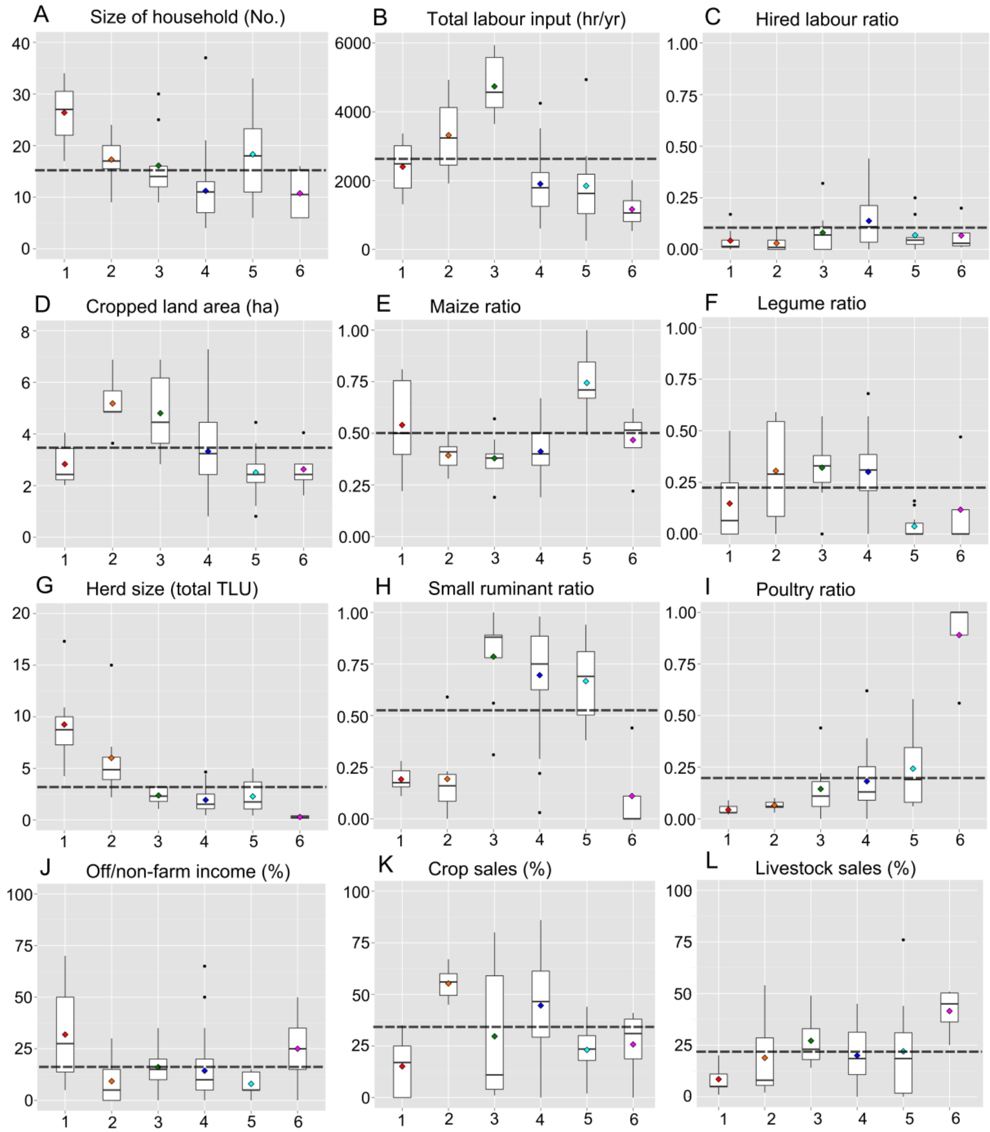


Figure 2.4. *Boxplots of variables for the six farm types based on: household (A), labour (B, C), land use (D-F), livestock (G-I) and income (J-L) dimensions. Boxplots show cluster means (coloured squares), median values (solid horizontal lines), the interquartile range containing the middle 50% of values (box outline), 90th percentile values (whiskers) and outlier values (closed circles). The survey means for each variable are represented by the dashed line.*

intervention community (Fig. 2.5A). This could be due to survey selection bias leading to under-coverage of Type 2 farmers, or scarcity of land compounded by the close proximity of neighbouring villages (Iddrisu Baba Mohammed, 2014: *pers. comm.*). The latter hypothesis seems plausible, given that mean surveyed farm sizes in Botingli were smaller than those of Tingoli or Kpalung.

The two crop variables retained in this study; maize ratio and legume ratio, bore a strong negative correlation to each other, suggesting that farms which dedicated large areas to maize did so at the expense of legume crops and *vice versa* (Fig. 2.2A). Furthermore, the share of land allocated to maize tended to increase as the overall cultivated area decreased (Fig. 2.2A). Studies in Ghana and elsewhere in Africa have shown that farm size correlates positively with holdings of livestock and other assets, and is a proxy for the wealth of a household, associated in turn with high-value crop production and market participation (Chapoto et al., 2013; Negash and Niehof, 2004; Tittonell et al., 2010). Results seem to indicate that less affluent households with smaller farms allocated more of their land to maize than their wealthier counterparts. For example, Type 5 households exhibited the smallest cropped areas and the highest maize ratio (Fig. 2.4E). Maize is the most widely consumed staple in the Northern Region and the higher proportion of this crop in Type 5 suggests that limited land resources may be preferentially allocated for production oriented toward food security (Chamberlin, 2007; Morris et al., 1999). Legumes, primarily produced as cash crops, were most abundant among some medium- and well-endowed farm households (Types 2-4). Well-endowed Type 1 did not follow this pattern, however; despite exhibiting considerable capital assets in the form of livestock, mean farm sizes were relatively small and cropped mostly to maize (Fig. 2.4D, E and G). This may be partially explained by their above-average engagement in non-farm income-generating activities (Fig. 2.4J) and apparent re-investment of that income in livestock rather than land.

2.3.2.3 Livestock

The rearing of livestock is a crucial form of fortification against (food) insecurity in Northern Ghana (Quaye, 2008). Livestock represents the most important store of value for farmers and the wealth of a household can be measured by the number and species of animals owned (Dercon, 1998; Dossa et al., 2011; Marchetta, 2013).

Cattle are the most valuable livestock and may be inherited- they are rarely sold except in times of extreme shock such as crop failure or famine (Laube, 2007). Results showed that Type 1 farm households possessed the most animals and the largest cattle herds, followed by Type 2 (Fig. 2.4G). The average share of marketed livestock products was also the lowest for these two farm types, demonstrating the farmers' capacity to accumulate assets that decrease their vulnerability (Fig. 2.4L). According to the literature, it is common for farmers to gradually stock their herds in response to favourable agricultural seasons when proceeds from crop sales may be re-invested in livestock (Tittonell, 2014). In addition to being stores of wealth that provide a buffer against shocks, the large cattle herds owned by Types 1 and 2 produce manure, thus putting these farmers at an advantage in terms of agronomic practices that may lead to improved soil fertility and crop productivity (Bellwood-Howard, 2012; Chikowo et al., 2014; Morris et al., 1999).

Small ruminants are less valued but are more commonly owned in the Northern Region due to their hardy and prolific nature. They may also be sold during stressful periods for immediate cash to purchase food or pay medical bills, for example (Laube, 2007). Except for Type 6, mean small ruminant numbers tended to be quite similar across farm types. The ratios, however, were highest for medium- to low resource endowed Types 3-5 (Fig. 2.4H).

Finally, almost all the sampled farm households kept a flock of family poultry as a source of quick cash, (sacrificial) gifts, and protein-rich food (Laube, 2007). Results indicated that the mean poultry ratio tended to increase as farm resource endowment decreased (Fig. 2.4I). Furthermore, the variables of poultry ratio and livestock sales were strongly positively correlated (Fig. 2.2B). Keeping poultry is financially economical for smallholders because little input (land, labour, capital) is required for the maintenance of a flock. This enables even those of the poorest strata in rural communities to make a profit from the sale of poultry products (Guèye, 2000). Type 6 exemplified this - it was characterized by a near total absence of any livestock besides poultry, while exhibiting the highest percentage of livestock sales (Fig. 2.4G, I and L). Tellingly, food self-sufficiency was also lowest for this type (*cf.* Annex 2), suggesting that the liquidation of livestock assets represented a coping strategy to cover household needs. Additionally, these farmers generally lack access to animal traction and organic fertilizers, resulting in low productivity of crop production which may further exacerbate food insecurity (Tittonell, 2014; Wiredu et al., 2010).

2.3.2.4 Labour

In Northern Ghana labour is an important factor of agricultural production, and a combination of family, hired and communal exchange labour is used (Quaye, 2008). Family labour is based on kinship ties and considered to be the traditional backbone of the rural workforce. The exchange labour system takes the form of 'work gangs'- farmers who pool their labour, taking turns working in different members' fields (Al-Hassan and Poulton, 2009). Wage labourers are hired on a seasonal basis for activities such as labour-intensive land preparation (Ngeleza et al., 2011).

Household size is commonly taken as a proxy for family labour availability, thereby positioning the hiring of help as a way to deal with family labour shortage (Mensah, 2015; Wiredu et al., 2010). Contrary to what we would expect, our results revealed only a weak negative correlation between the hired labour ratio and household size (Fig. 2.2A). This might be explained by the fact that a healthy exchange labour system exists in the study area (Iddrisu Baba Mohammed, 2014: *pers. comm*.), which seemed to absorb most labour demands, thus keeping the mean hired labour ratio low across farm types.

Results also suggested that total on-farm labour input per year (family-, exchange and hired labour) was highest amongst households with larger cropped areas and/ or animals herds (Types 1-3), presumably due to the correspondingly higher work and maintenance requirements (Jayne et al., 2003).

Finally, the variables of total labour input and legume ratio were positively correlated (Fig. 2.2), probably attributable to the higher labour-intensity required for legume (especially groundnut) cultivation (Franke et al., 2010).

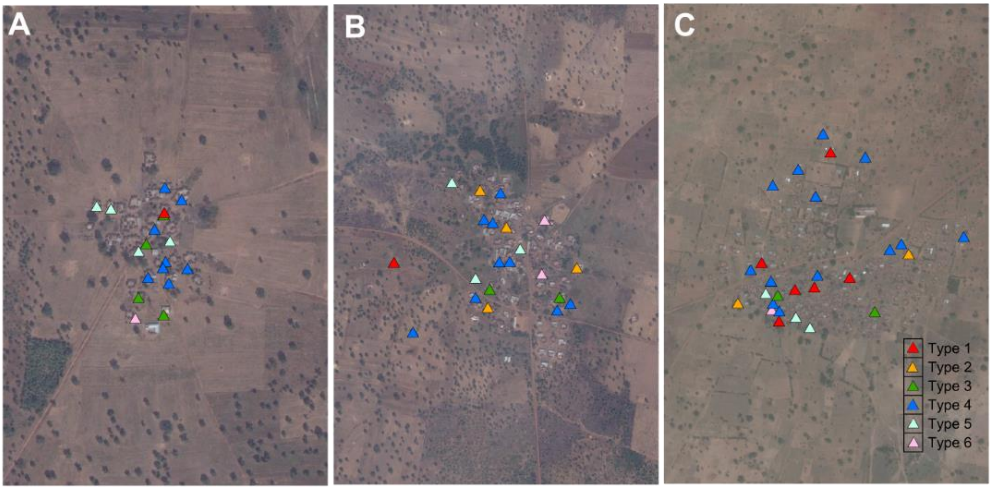


Figure 2.5. *Maps showing the spatial distribution of identified farm types in the three Africa RISING intervention communities in Ghana's Northern Region: Botingli (A), Kpalung (B) and Tingoli (C).*

2.3.2.5 Income

Shortfalls in agricultural production are common in the harsh agro-ecological conditions of the Northern Region, compelling rural households to diversify their livelihoods (Chapoto et al., 2013; Ellis, 2008; Owusu et al., 2011). Income may be sourced from on-farm (crop- and livestock income), off-farm (agricultural income), and non-farm activities (non-agricultural income) (Ellis, 1998).

Recorded sources of off-farm income in the case-study area included casual wage labour on other farms, while non-farm income sources included trading, remittances, artisanal activities, salaried work and transport services (in order of recorded frequency). Nevertheless, dependence on off/non-farm income sources was found to be quite low among most farm types (Fig. 2.4J). This may be explained in part by the remoteness and associated dearth of off-farm opportunities in the Northern Region, compared to the rest of the country (Chamberlin, 2008; Kelly and Bening, 2007). However, the average share of off/non-farm income for high resource endowed Type 1 was exceptionally high at 32%, and for low resource endowed Type 6 the corresponding percentage was also relatively high at 25% (Fig. 2.4J).

Research on rural livelihood strategies suggests that more affluent farmers may be better disposed to participate in non-farm work (Owusu et al., 2011) and as incomes increase, farm households tend to shift their investments to non-agricultural activities (Adjei-Nsiah et al., 2007b; Frelat et al., 2016; Wiredu et al., 2010). According to the survey data, the majority of the Type 1 farmers were involved in trading of one kind or another. Less affluent households, on the other hand, tend to depend on agriculture or are generally limited to low-paid activities in the off-farm sector, such a seasonal work as hired labourers on the farms of wealthier neighbours (Chamberlin, 2008; Ellis, 2008; Marchetta, 2013). However, none of the Type 6 farmers indicated involvement in casual labour. On the other hand, a third were recipients of remittances; a complementary source of income resulting from rural-urban migration. Migrant households are reportedly smaller (Adams et al., 2008; Davis et al., 2007) and labour constrained (Adaku, 2013) due to out-migration of able-bodied household members- characteristics consistent with Type 6.

Finally, analysis of the spatial allocation of farm types revealed that 75% of the Type 1 farm households were located in Tingoli, a community situated in close proximity to the market town of Nyankpala in Tolon-Kumbungu, which is also the base of a number of agricultural research and development institutions (Fig. 2.5C). The distance to market can be used as a determinant of non-farm income (Marchetta, 2013), while travel out of the community to urban areas provides exposure to new information and technologies (Morris et al., 1999). This finding suggests, therefore, that superior access to expert knowledge on improved farming practices as well as off/non-farm opportunities may have played a role in the developmental trajectory of farm households in Tingoli.

2.3.3 The typology as a framework for innovation targeting

The communities of the case-study area comprise farming systems with heterogeneous characteristics. The suitability of potential agricultural support measures should therefore be assessed in relation to type-specific farm household opportunities and constraints, using the established typology as a framework (Douxchamps et al., 2015a; Emtage et al., 2007; Norman and Collinson, 1985; Tittonell et al., 2010)(Table 2.3). Nevertheless, we recognize that it is challenging to fully capture the diversity of the farming systems and acknowledge the limitations of the typology in this regard. The following sections reflect on these two points.

2.3.3.1 Opportunities and constraints for targeting

a) High resource endowed farms

The typology revealed that 21% of the sampled farm households were relatively well-endowed, comprising Types 1 and 2. It appears that endowed households employ a broader range of strategies against production-related risks, such as diversification into higher value crops, collective marketing, (bulk) purchase of inputs, and the judicious sale of some assets (Dercon, 2002; Quaye, 2008; Wiredu et al., 2010). Furthermore, their characteristics may facilitate wider exploration of opportunities for farm development (Type 2) as well as 'stepping out' (Dorward et al., 2009; Tittonell et al., 2010) into non-farm activities (Type 1). This has implications for innovation targeting. For example, the large farm sizes of Type 2 allude to greater investment in on-farm activities, and thus better incentives for adoption of improved agricultural technologies and practices (Morris et al., 1999). The larger household sizes associated with Type 1, in turn, may increase the likelihood of experimentation with diverse crop combinations and varieties in order to accommodate the diverse preferences of household members (Bellwood-Howard, 2012; Etwire et al., 2013). Additionally, these farm types could be encouraged to adopt practices that ensure more efficient collection, storage, and use of the manure supplied by their large cattle herds (Quansah et al., 2001). Importantly, due to inter-household interactions, innovations that are taken up by more affluent farm households may have (unintended) effects beyond the spaces in which they operate. For example, if a farmer invests in a tractor, he or she might hire out that tractor to other farmers in the community for a nominal fee, thus conferring 'spill-over' benefits to those who cannot afford to purchase a tractor (Chapoto et al., 2013).

b) Medium resource endowed farms

The largest share of the surveyed farm households were classified as moderately-endowed (59 %), comprising Types 3 and 4. According to the 2007 MoFA study which disaggregated smallholders in 16 districts of Northern Ghana depending on their livelihood strategies, medium-endowed farmers pursue a 'development strategy' (Devereux and Sabates-Wheeler, 2008). This strategy was based on saving through livestock (with resources acquired from crop sales or livestock husbandry) leading to both farm and off/non-farm investment along with increased responsiveness to commercial farming opportunities. Our study revealed a similar pattern, with Type 3 characterized by medium sized small ruminant herds, moderate to large farm areas allocated to cash crops and some sales of assets. Type 4 exhibited comparable features, albeit at smaller dimensions.

Table 2.3. *Main implications of the farm typology for targeting of agricultural interventions in Savelugu-Nanton and Tolon-Kumbungu districts of Ghana's Northern Region.*

	Opportunities and constraints	**Implications for targeting**	**Farm Types**					
			1	**2**	**3**	**4**	**5**	**6**
Opportunities	High availability of family labour	Promote profitable but potentially labour-intensive technologies and practices	**x**	**x**			**x**	
	Access to animal traction	Promote traction tools for reducing drudgery of land preparation, seeding and weeding	**x**	**x**				
	Access to manure	Encourage practices that ensure more efficient collection, storage, and use of manure supplied by cattle herds, and promote (targeted) manure application to crops	**x**	**x**				
	Higher farm investment capacity	Promote improved agricultural technologies, inputs and practices (*e.g.* improved seed, fertilizers, irrigation)	**x**	**x**	**x**	**x**		
	Experience with diversified crop production	Increase multi-cropping, intercropping, crop rotation and new crop varieties use		**x**	**x**	**x**		
	Responsive to commercial farming opportunities	Promote high value crops, improve marketability		**x**	**x**	**x**		
	Higher investment in livestock herd	Improve crop-livestock integration and promote multi-purpose crops (*e.g.* food-fodder crops) and leguminous fodder	**x**	**x**				
Constraints	Low availability of family labour	Support adoption of time saving practices and low-cost alternatives for transportation and tillage traction			**x**	**x**		**x**
	Difficulty accessing manure	Promote use of nitrogen-fixing legumes (as green manures, intercrops, fodder crops *etc.*) and composting of crop residues and household waste			**x**	**x**	**x**	**x**
	Higher food insecurity	Increase farm productivity, promote high yielding food crop varieties, improve post-harvest storage facilities				**x**	**x**	**x**
	Poverty (cash flow constraints, hand-to-mouth existence)	Promote low-input technologies with improved resource use efficiency, support access to inputs at the beginning of the cropping season, improve farmers' ability to accumulate capital and reinvest in their farms					**x**	**x**

These types could be described as 'stepping up' (Dorward et al., 2009; Tittonell et al., 2010). In terms of targeting, then, opportunities for agricultural expansion and optimization may be investigated, especially for more vulnerable and heterogeneous Type 4 which represents the bulk of the surveyed households and appears to be straddling the boundary between low- and medium endowment.

However as previously described, the smaller households of the latter tend to limit the manpower available for on-farm labour, thus driving up the hired labour ratio. This should be taken into account if potentially labour-intensive technologies or practices are to be promoted, such as legume production intensification (Franke et al., 2010). Regarding livestock integration, the majority of medium resource endowed farmers do not own any cattle or kraals. Therefore innovations such as the use of compost as a soil amendment or the procurement of donkeys as a low-cost alternative for transportation and tillage traction, as suggested by Bellwood-Howard (2012), may be considered.

c) Low resource endowed farms

Poorly-endowed households comprised 20% of the surveyed sample and were represented by Types 5 and 6. These seemed to correspond to the 'poor' and 'vulnerable' groups identified by MoFA (2007) respectively; considered to be particularly exposed to risk as a result of constrained resources (typically a few inherited assets). These farm households could be described as 'hanging in' (Dorward et al., 2009; Tittonell et al., 2010), a situation where vulnerability reduces possibilities for saving and investment, and maintenance of the current livelihood through subsistence farming is the priority. When hit by a shock, they may be forced to adopt a 'survival strategy' simply in order to cover immediate expenses (Devereux and Sabates-Wheeler, 2008). Invariably, this implies the sale of household valuables such as livestock, food rationing, petty trade, cheap wage labour, migration, withdrawal of children from school or reliance on communal support networks for assistance (Al-Hassan and Poulton, 2009; Chamberlin, 2008; MoFA, 2007; Quaye, 2008). Tactics such as these often result in a downward spiral, reducing even further any opportunities to climb out of the 'poverty trap' (Tittonell, 2014).

Impoverished households thus face the strongest constraints to investing in new technologies and therefore, interventions should focus on alleviating basic challenges such as food insecurity; while innovations should be geared towards improving these farmers' ability to accumulate capital and reinvest in their farms (Chapoto et al., 2013). For example, low resource endowed households tend to struggle to achieve food self-sufficiency (Fig. 6 and Annex 2), often selling their produce immediately after harvest when prices are lowest to meet immediate cash needs, as well as purchasing food supplies for the rest of the year (Tittonell, 2014). Better post-harvest storage facilities may benefit such farmers, allowing them to store produce for home consumption and sell later in the season when prices are higher (Morris et al., 1999; Quaye, 2008).

Because poorer farmers tend to depend on wealthier cattle owners for animal traction and manure (Tittonell, 2014), the possibilities for redressing this imbalance through alternative tillage traction options (as described for medium-endowed farmers) or the use of compost or poultry manure as fertilizer, may be investigated (Bellwood-Howard, 2012). Furthermore, while barriers to non-farm work should be reduced, thus enabling livelihood opportunities beyond the farming sector (Type 5), policies should also be geared towards dealing with loss of on-farm labour (to migration, for example– Type 6) (Marchetta, 2013). Finally, it is acknowledged that instead of promoting isolated solutions or single technological innovations, strategies for lifting poor households above certain critical thresholds would have to trigger complete 'system shifts' in order to induce sustainable change (Tittonell, 2014).

2.3.3.2 Typology limitations

It is challenging to fully capture the diversity encountered in the farming systems of the study area and it is recognized that the typology is limited in its ability to accurately represent every variation that exists (Cortez-

Arriola et al., 2015; Iraizoz et al., 2007; Landais, 1998). For example, the smallest identified cluster, Type 6, represents the most vulnerable group of the typology, and it could be argued that development efforts should prioritize these households. However, it appears that other categories of groups widely considered to be vulnerable in rural Ghana were absent from the surveyed sample, such as landless and female headed households (Yaro, 2010a). Furthermore, given the small sample size, the distinction between true outliers (*i.e*. observations that were not representative of the sample, such as positive deviants) and artificial outliers (*i.e.* observations that were representatives of small, under-sampled sub-groups) was hard to make. Hence, a trade-off between the representative quality and level of manageable detail of the typology had to be negotiated in the classification process (Hair et al., 2010). Added to this is the dynamic nature of agriculture which guarantees that typologies expire- they only provide a fleeting snapshot of farm situations in time (Emtage et al., 2006; Kostrowicki, 1977).

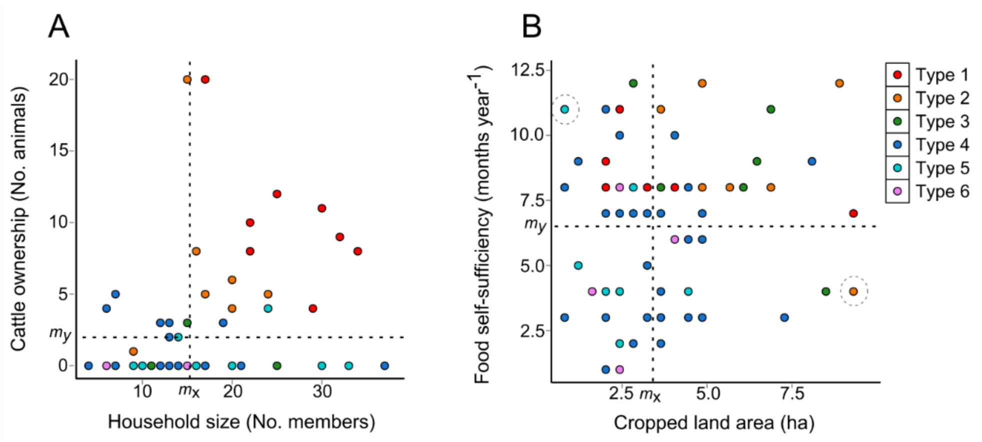


Figure 2.6. *The six farm types are plotted against their household size and cattle ownership (A), and their cropped land area and food self-sufficiency (B). The survey means (m_y) for the plotted variables are represented by the dashed lines. Encircled points are observations that deviate from the typical characteristics of their group (cf. Section 2.3.3.2 for further explanation).*

All these complexities are reflected in the farm types themselves, which should therefore be interpreted with caution. For example, while analysis of livestock ownership patterns allowed for clear differentiation between larger households that tended to own cattle (Types 1 and 2) and smaller ones that tended not to (Fig. 2.6A), the relationship between farm size and food self-sufficiency revealed a fuzzier reality. Figure 2.6B highlights a severely land-constrained Type 5 household with high food self-sufficiency, and a well-endowed Type 2 household with below-average food self-sufficiency. The atypical characteristics of these two farm households diverged from a mean profile of farm types which seemed to imply that higher resource endowed types enjoyed higher levels of food self-sufficiency than their lower resource endowed counterparts, on average (*cf.* Annex 2). Such cases may reflect survey inaccuracies attributable to erroneous farmer estimates, or they may reflect the limits of standard survey representations, which often fail to capture the more intangible dimensions of rural livelihoods such as (lack of) extra-household social relationships, networks, *etc*. (Randall and Coast, 2015).

2.4. Conclusions

While the typology revealed the general underlying structure of farming system heterogeneity, the complex and dynamic coexistence of diverse farm households in space and time was only partially captured, as neither un(der)-represented groups nor system trajectories were specifically accounted for. Nevertheless, analysis of the established farm types suggests that the patterns of their persistence are rooted in the self-reinforcing 'poverty traps' of a system which privileged wealthier over poorer farmers. These patterns of persistence allowed identification of the most promising targeting pathways for improvement of farmer livelihoods. R4D programs seeking to sustainably intensify agricultural production in the target communities should take into account the opportunities and constraints identified across the farm types and tailor their development strategies, interventions and policies accordingly. The results of this typology analysis will be used in the Africa RISING project for further analysis of suitability of entry points for farm and livelihood improvement. For each of the farm types, the effects of interventions proposed by the project will be evaluated for productive, socio-economic and environmental performance in participatory, model-based studies and on-farm experimentation (Groot et al., 2012; Groot and Rossing, 2011). It is expected that the type-specific exploration of trade-offs and synergies among performance indicators and the further analysis of intra-household interactions and dynamics will allow formulation of innovation pathways that are appropriate for each level of endowment and livelihood strategy as captured in the typology (Cortez-Arriola et al., 2016).

Further insight into the drivers of diversity and its consequences might be gained through incorporation of complementary perspectives on farming system diversity, for example through the participation of farmers themselves in typology construction. It has been suggested that while quantitative, objective techniques provide reproducible and generalizable results; qualitative, participatory methods potentially deliver greater depth of understanding of the complexity of local circumstances and are useful for contextualizing heterogeneity within the rural landscape (Emtage et al., 2007; Kuivanen et al., 2016b; Whatmore, 1994). Therefore, it is recommended that future typological studies go a step further and adopt a more flexible approach by incorporating qualitative and quantitative; participatory and statistical methods (Alvarez et al., 2014; Den Biggelaar and Gold, 1995; Pacini et al., 2014; Righi et al., 2011).

Chapter 3

3. Farm and farmer diversity

Based on:

Kuivanen, K.S., **Michalscheck, M.**, Descheemaeker, K., Adjei-Nsiah, S., Mellon-Bedi, S., Groot, J.C.J., Alvarez, S., 2016. A comparison of statistical and participatory clustering of smallholder farming systems - A case study in Northern Ghana. J. Rural Stud. 45, 184–198. https://doi.org/10.1016/j.jrurstud.2016.03.015

You may access the article online by scanning the QR-code with a mobile device.

Abstract

Typologies are often used to understand and capture smallholder farming system heterogeneity, and may be derived using different approaches and methods. This article aims to compare a quantitative, statistical typology based on a survey dataset and multivariate analysis, with a qualitative, participatory typology based on informal group sessions and activities with local stakeholders from three communities in Northern Ghana. The statistical typology resulted in six clusters, with farm households categorized on the basis of their structural (resource endowment) - and functional (production objectives/ livelihood strategies) characteristics. The participatory typology identified five farm types, based primarily on endowment (farm size, income investment), gender and age-related criteria. While the entire household was adopted as the unit of analysis of the statistical typology, the participatory typology provided a more nuanced differentiation by grouping individual farmers; with possibly several farmer types per household (*e.g*. 'small' and 'female farmers') as well as 'farm-less' individuals as a result. Other sources of dissimilarity which contributed to limited overlap between the typologies included changes that occurred in the communities between the two data collection efforts and inaccuracies in the data. The underlying causes of the latter seemed to mainly relate to socio-cultural issues that distorted information collection in both typologies; including power and status differences between both the researchers and farmers, as well as the farmers themselves. We conclude that although statistical techniques warrant objectivity and reproducibility in the analysis, the complexity of data collection and representation of the local reality might limit their effectiveness in selection of farms, innovation targeting and out-scaling in R4D projects. In addition, while participatory typologies offer a more contextualized representation of heterogeneity, their accuracy can still be compromised by socio-cultural constraints. Therefore, we recommend making effective use of the advantages offered by each approach by applying them in a complementary manner.

Keywords: farming systems; heterogeneity; Northern Ghana; participatory research; typology

3.1. Introduction

In Sub-Saharan Africa, the primary producers of agricultural outputs are smallholder farmers, who account for 80% of all farms in the region (AGRA, 2014). Smallholders are perceived to share certain characteristics which differentiate them from larger-scale, profit-driven producers. Such characteristics include: limited access to land, financial capital and inputs, high levels of vulnerability and low market participation (Chamberlin, 2008, 2007). However, far from being homogeneous; like farms everywhere, smallholdings are adapted to the conditions of their biophysical, economic, and socio-institutional environments (Ruthenberg, 1971). In this study, a farming system is defined as the complex of resources that are arranged and managed according to the totality of production and consumption decisions taken by a farm household, including the choice of crops, livestock, on-farm and non/off-farm enterprises (Fresco and Westphal, 1988; Köbrich et al., 2003). The process of adapting to different macro- and micro-level contexts has resulted in a rich diversity of smallholder farming system configurations at all scales (*i.e.* household, village, region and country) across the African continent (Giller, 2013; Tittonell et al., 2010) This diversity is made manifest spatially (*e.g*. based on resource endowment), temporally (by virtue of their openness, farming systems are dynamic) and in farmer strategies (Mortimore and Adams, 1999; Ruthenberg, 1971).

A practical way of distinguishing patterns in populations of heterogeneous smallholder farming systems is by stratifying farms into subsets or groups according to specific criteria (Andersen et al., 2007; Van den Brand, 2011). Farm typologies attempt to perform such groupings; the term 'typology' designating both the science of type delineation and the system of 'types' resulting from this procedure (Landais, 1998). The use of typologies has a long tradition in rural sociology (Whatmore et al., 1987) and has attracted the attention of agricultural scientists who create typologies in an attempt to find a meaningful compromise between analysing single farms (no farming system is organized exactly like any other) and assuming broad categories such as smallholders in general.

Farm typologies may be constructed for different purposes; such as to identify diversity and its underlying causes (Gaspar et al., 2008; Tittonell et al., 2005), analyse agricultural trajectories (Iraizoz et al., 2007) or support the development (selection of farms), implementation (targeting and scaling-out of novel technologies or innovations) and monitoring (scaling up of impact assessments) of agricultural development projects (Alvarez et al., 2014; Byerlee et al., 1988; Emtage et al., 2007). Furthermore, farm typologies can focus on different aspects of a farming system; with some looking at differences at field level (Andersen et al., 2007; Carmona et al., 2010; Dossa et al., 2011; Zorom et al., 2013), and others focusing on household-level diversity in resource endowment, for example (Iraizoz et al., 2007; Righi et al., 2011; Tittonell et al., 2010). Finally, different approaches to typology construction can yield different results and this will affect the relevance of the resulting types for all stakeholders involved.

The approach and methodology used to construct a typology is embedded in specific epistemological assumptions which determine the research paradigm (Whatmore et al., 1987). Social scientists and practitioners of participation frequently rely on qualitative evidence, while natural scientists and economists tend to favour 'hard data'. Meanwhile, governments and donors often leave decisions about research approaches to the technical advisers involved in agricultural research and development (Barahona and Levy, 2005). In response to the need to look beyond the conventional, top-down, transfer-of-technology models for agricultural research and extension of the 1990s, which often failed to achieve the required impact for many smallholders in Africa (Chambers and Jiggins, 1987), recent discourse has focused on the potential and limits of alternative participatory approaches (Asten et al., 2009; K. Jones et al., 2014; Kudadjie et al., 2004; Neef and Neubert, 2011).

The epistemological perspectives in the theoretical debate surrounding the development of farm typologies and their utility has been reviewed by Whatmore (1994) who identified three approaches to farm clustering. The first is the taxonomic or 'positivist approach', which defines types based on quantitative data, according to standard scientific protocols with the choice of variables usually determined by the researcher. The second approach is more explanatory and is termed the 'relational approach'; it challenges the dominant positivist approach with its emphasis on the identification of relations between farmers and their contexts to help explain causal processes. The third is the more interpretive yet similarly unorthodox 'folk approach', which incorporates the qualitative, subjective processes (motivations, meaning-making *etc*.) behind the patterns of behaviour, relationships and strategies of the participants into the typology. In the latter, the participants themselves usually determine the criteria for grouping of farmers or farm systems. In a similar vein, Maton et al. (2005) discriminate two kinds of farm typologies: those using 'positivist' methods based on statistical data (Köbrich et al., 2003) and those using 'constructivist' methods based on expert knowledge (Girard et al., 2001; Landais, 1998). Although it is acknowledged that the boundaries between these different frameworks are not rigid, the spectrum of approaches to the study of farm diversity generally has the positivist approach and the folk approach as its extremes (Emtage et al., 2007). The 'etic-emic' distinction employed by anthropologists is particularly useful for further differentiating them.

The positivist approach takes as its starting point theories and concepts from outside of the studied setting, regarded as meaningful and appropriate by scientists ('etic' perspective) (Lett, 1990). Most farm typologies have been constructed within the positivist framework (Whatmore et al., 1987). Farm diversity is studied using quantitative variables that are believed to have strong relations with the variation in the systems under investigation, and clustering arises from multivariate statistical analysis of these variables (Bidogeza et al., 2009; Chavez et al., 2010; Tittonell et al., 2010). Strengths of this top-down approach are its reproducibility and transferability (ease of comparison across scales and contexts) (Kostrowicki, 1977). However, by depending on researcher-defined criteria, important drivers of diversity may be overlooked and the identified categories may lack meaning for farmers themselves (Pacini et al., 2014; Van Averbeke and Mohamed, 2006). Obtaining complete quantitative data is often also costly and time-consuming due to the diversity and the complexity of farming systems (Thornton and Herrero, 2001).

In the folk approach, the intent is to discover how members of a system perceive and classify diversity (McKinney, 1969; Sims and Bentley, 2002). Constructs are expressed in terms that are meaningful and appropriate to local perspectives and indigenous knowledge (‘emic’ perspective) (Lett, 1990) and as a result, data collection tends to emphasize participatory methods (Adjei-Nsiah et al., 2007b; Kong et al., 2014). The main strength of this qualitative, bottom-up approach is the attention paid to situating the typology in the local context, which provides room for unexpected patterns and concepts to emerge (K. Jones et al., 2014). For example, the criteria of classification used by farmers usually differ in interesting ways from those used by scientists (McKinney, 1969; Nazarea, 2006). One of the weaknesses of the folk approach is that it lacks the authority of the scientific method. Its subjectivity renders it difficult to measure the identified categories and its specificity makes it ill-suited to generalization beyond its local boundaries (Van Averbeke and Mohamed, 2006). Research using participatory methods may also be costly in terms of resources and time spent by researchers and stakeholders who take part in the studies (Barahona and Levy, 2005; Neef and Neubert, 2011; Röling et al., 2004).

Notwithstanding the somewhat polarized debate on the value of participation for agricultural research and development (Barahona and Levy, 2005; K. Jones et al., 2014; Sims and Bentley, 2002), participatory approaches have encountered both successes and failures worldwide (Asten et al., 2009; Bentley, 1987; Johnson et al., 2004; Lilja and Dixon, 2008; Scoones and Thompson, 1994). Improving the effectiveness of positivist approaches to typology construction by combining participatory methods in a way that will make research more useful for farmers in their own local context remains a methodological challenge (Kudadjie et al., 2004; Neef and Neubert, 2011). Nevertheless, careful integration of expert and scientific knowledge can potentially lead to a more comprehensive understanding of complex and dynamic farming systems (Righi et al., 2011).

The aim of this study is to compare the positivist (statistical) and folk (participatory) approaches to typology construction. Specifically, we assess the (non-)complementarity of a statistical typology described in Kuivanen et al. (2016a) and a participatory typology elaborated in this paper, for characterisation of smallholder farming systems in three intervention communities of an active Research for Development (R4D) project in Northern Ghana. The statistical typology was generated using recent survey data, and incorporated quantitative variables of farm structure- and functioning. Clustering arose from multivariate statistical analysis of these variables, using the well-known techniques of principal component analysis and cluster analysis. The participatory typology was delineated in collaboration with local stakeholders, using their expert knowledge to establish a common reference base. This paper thus sets out to: (*i*) describe the results of the participatory typology; (*ii*) compare the variables of the statistical and participatory typologies, and (*iii*) analyse the overlap between the systems of farm types. Following this, we reflect on the possible causes of the dis(similarity) between the two approaches and conclude on the insights offered by each approach in the context of agricultural development. It is envisioned that the results will support the more effective design and execution of development interventions and policies that are tailored to the different needs and opportunities of local farmers.

3.2. Materials and methods

3.2.1 Project, site selection and data sources

This research was embedded in a multi-country R4D program, Africa Research in Sustainable Intensification for the Next Generation (Africa RISING), supported by the United States Agency for International Development as part of the United States government 'Feed the Future' initiative (http://africa-rising.net/). Operating within a time horizon of five years (2012-2016), the project is being implemented in East and Southern Africa (Ethiopia, Tanzania, Malawi and Zambia) and in West Africa (Mali and Ghana). In partnership with selected intervention communities, Africa RISING aims to create opportunities for smallholder farm households to escape hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, while conserving or enhancing the natural resource base (IITA, 2012). The challenge is to achieve these goals while acknowledging smallholder diversity within the project regions and communities. Therefore, identification of farm types is an important first step.

Africa RISING in Ghana is led by the International Institute of Tropical Agriculture (IITA) and the intervention area comprises the three most poverty-stricken geographical and administrative regions in Northern Ghana, namely the Northern Region, Upper East Region, and Upper West Region (Fig. 2.1). In September 2013, a team of enumerators associated with Africa RISING surveyed 240 farm households across these three regions of Northern Ghana, as part of a baseline study. In each region, 80 household heads were randomly selected from Africa RISING intervention communities for interviews using a structured questionnaire. Basic information on household composition and education of household members, land holdings, livestock ownership, labour use, assets, housing, production orientation, major crops and sources of income was collected. This study makes use of the resulting dataset, but focuses exclusively on the classification of farm households in the Northern Region.

3.2.2 Characteristics of the case-study area

The Northern Region occupies 70 383 km^2 which constitutes over two fifths of the area of Ghana. Divided into 20 districts with the town of Tamale as its regional capital, the region is economically poor with little industry (Kelly and Bening, 2007). Vegetation falls into the Guinea-Savannah zone, which is characterized by vast, low-lying areas of semi-arid grassland interspersed with savannah woodland, a dry and hot climate, unimodal rainfall and fragile, sandy-loam soils often overlying impenetrable ironpan or laterite (Ellis-Jones et al., 2012; Wiredu et al., 2010). Three Africa RISING intervention communities were surveyed within the Northern Region; namely Botingli (9.61° N 0.79° W, Savelugu-Nanton district *n*=21), Kpalung (9.68° N 0.78° W, Savelugu-Nanton district, *n*=28) and Tingoli (9.37° N 1.01° W, Tolon-Kumbungu district, *n*=31) (Fig. 2.1). These communities constituted the study area.

The predominant ethnic group in the study communities are the Dagomba (Table 3.1), who comprise about a third of the population of the Northern region (Ellis-Jones et al., 2012). Their basic unit of social organization is the farm household, physically centred around a 'compound' where the head (typically male) lives with his nuclear or extended family (Al-Hassan and Poulton, 2009; Oppong, 1967). Livelihoods are based on small-scale, low-input, mixed crop-livestock agriculture and villages tend to follow the typical concentric spatial arrangement found elsewhere in Africa, comprised of nucleated human settlements in the middle, inner rings of fertile compound farms, medium distance fields, and outer rings of more distant bush farms (Benneh, 1973; Yiridoe et al., 2006).

According to the traditional land tenure system, arable land inherited by the household head through paternal lineage is fragmented into smaller plots that are allocated to household members (Iddrisu Baba Mohammed, 2014: *pers. comm*.). While responsibility for growing the household's maize staple crop lies with the head and is grown on his plot (the main compound farm), all household members are expected to contribute labour, so as to ensure a basic level of staple food supplies for the domestic unit (Al-Hassan and Poulton, 2009). In addition, household members cultivate different combinations of cash- and food crops on their own farms, which may be sold in the event of surpluses (Table 3.1). Livestock are kept for food, income, wealth accumulation, sacrificial purposes and to a lesser extent for their supply of inputs such as manure (used as organic fertilizer) and draught power (Ellis-Jones et al., 2012; Sansoucy et al., 1995). The characteristics of the communities are further summarised in Table 3.1.

__Table 3.1__. Main characteristics of the case-study communities in Ghana's Northern Region (2013 cropping season).

Characteristic	Savelugu-Nanton		Tolon-Kumbugu
	Botingli	**Kpalung**	**Tingoli**
Socio-economic			
Population	579	1739	2266
Ethnic groups	Dagomba	Dagomba, Fulani, Frafra and Mamprusi	Dagomba
Religion(s)	Islam and traditional faiths	Islam, traditional faiths	Islam, Christianity, traditional faiths
Distance to closest urban centre	3 km	7 km	2 km
Land availability	Scarce	Abundant	Scarce
Access to major markets	Intermediate	Relatively poor	Relatively good
Production activities			
Major food crops	Maize (Zea mays)	Maize, yam (Dioscorea sativa)	Maize
Major cash crops	Soybean (Glycine max) and groundnut (Arachis hypogaea)	Soybean, groundnut	Pepper (Capsicum chinense), groundnut
Livestock system	Free grazing local livestock breeds (cattle and small ruminants), night corralling	Herding by Fulani, free grazing and night corralling (cattle and small ruminants)	Free grazing local livestock breeds (cattle and small ruminants), night corralling, traction, pig husbandry

3.2.3 Statistical typology

The Africa RISING survey for the Northern Region comprised information from 80 randomly sampled farm households across the three case-study communities, capturing the diversity in local farming systems (Table 3.2). The dataset was used by Kuivanen et al. (2016a) to construct a statistical farm typology.

Table 3.2. *Main characteristics and heterogeneity of the farming systems in the case-study area (n=80 surveyed farms) and the variables used for their categorization in the statistical typology ('Incl. in PCA') and the resulting farm types (1-6) and their distribution (HRE: High Resource Endowed; MRE: Medium Resource Endowed; LRE: Low Resource Endowed; SRC: Severely Resource Constrained).*

Variable	Unit	Incl. in PCA	Code	Mean	±SEM	Min.	Max.
Household[a]							
Size of household	Number of members	✓	sizehh	15.2	0.97	4	37
Age of household head	Number of years			48.0	1.61	21	70
Labour							
Total labour input[b]	Hours per year	✓	totlab	2450.5	174.22	256	7048
Hired labour ratio[c]		✓	hiredratio	0.1	0.01	0	0.44
Female labour ratio[d]				0.2	0.02	0	0.57
Land use							
Cropped land area[e]	Hectares	✓	landsize	3.8	0.24	0.81	9.31
Maize ratio[f]		✓	maizeratio	0.5	0.02	0.19	1
Legume ratio[g]		✓	legratio	0.2	0.02	0	0.68
Tuber ratio[h]				0.1	0.02	0	0.51
Other cereal ratio[i]				0.1	0.01	0	0.33
Livestock ownership							
Herd size	TLU[j]	✓	tottlu	3.2	0.39	0.15	17.31
Cattle ratio[k]				0.2	0.04	0	0.93
Small ruminant ratio[l]		✓	rumratio	0.6	0.04	0	1
Poultry ratio[m]		✓	poultryratio	0.2	0.03	0	1
Food security and income							
Food self-sufficiency[n]	Months per year			6.6	0.36	1	12
Crop sales[o]	Percentage	✓	cropsales	36	3	0	86
Livestock sales[p]	Percentage	✓	livsales	21	2	0	76
Off/non-farm income[q]	Percentage	✓	offincome	16	2	0	70

Type	Main characteristics	Proportion in survey
1	HRE, large cattle herd, ample off/ non-farm activities	11%
2	HRE, large farms, market orientation	10%
3	MRE, small ruminants, on-farm labour intensive	13%
4	MRE, small ruminants, ample hired labour	46%
5	LRE, maize-dominated, few off/non-farm activities	14%
6	SRC, livestock sales, ample off/non-farm activities	6%

[a]*A 'farm household' within Africa RISING is defined as a group of people that work and live at least half of the time on the farm and operate under the leadership of a household head* (IITA, 2012); [b]*Family, hired- and exchange labour input for crop production (the sum of all reported labour per plot per household);* [c]*Share of the total labour which is hired (hired labour/total labour input);* [d]*Share of the total labour which is undertaken by women (female labour/total labour input);* [e]*Land used by farmers for crop production (the sum of all reported plot sizes per household);* [f]*Share of arable land cropped to maize;* [g]*Share of arable land cropped to legumes: soybeans, groundnuts, cowpeas;* [h]*Share of arable land cropped to roots and tubers: cassava and yam;* [i]*Share of arable land cropped to other cereals: rice, sorghum, millet;* [j]*Tropical Livestock Unit: livestock conversion factors based on Jahnke et al.* (1987); [k]*Share of cattle in total TLU (herd);* [l]*Share of small ruminants in total TLU (herd): goats and sheep;* [m]*Share of poultry in total TLU (herd): chickens, ducks, turkeys, pigeons and guinea fowls;* [n]*Months of the year when household food demands are met by on-farm production;* [o]*Share of crop products sold on the market;* [p]*Share of livestock products sold on the market;* [q]*Share of income derived from off/ non-farm activities.*

Variables

From the pool of farm household-level information, 12 variables describing household, labour, land use, livestock ownership and income dimensions were distilled (Table 3.2). The choice of variables was informed by the findings of previous studies, project objectives and data availability.

Methods

Two multivariate statistical techniques were employed sequentially: principal component analysis (PCA) to reduce the dataset into non-correlated principal components (PC's) and cluster analysis for partitioning the PCA output into clusters. For the latter, a two-step approach was followed. First, a hierarchical, agglomerative clustering algorithm using Ward's method was employed to define the number of groups (*k*), and then a non-hierarchical, partitioning algorithm was employed to refine these *k*-groups. All analyses were executed in R (version 3.1.0) with the *ade4* package (version 1.6-2, available online at: http://pbil.univ-lyon1.fr/ADE-4/) and the *cluster* package (version 1.15.2).

Results

The results of the multivariate analysis (*i.e.* variable correlations, PC interpretation, farm types) are illustrated in Figure 2.2. The PCA extracted the first five PC's explaining about 66% of the variability in the dataset. Six farm types were identified; contrasted by their structural (resource endowment[2]) - and functional (production objectives/ livelihood strategies) characteristics (Fig. 2.2E-2H, Table 3.2 and Table 3.4). Types 1 and 2 tended to be the wealthiest; *i.e*. relatively well endowed in terms of land, livestock and human resources. Type 1 comprised large households endowed with sizeable cattle herds, medium sized maize-based farms and high levels of income diversification into non-farm

[2] This refers to wealth-related criteria such as farm size, livestock ownership and household size (Tittonell et al., 2010).

sectors such as trading. Type 2 was represented by households with relatively large farms cropped primarily to maize and legumes. Income was mainly generated through the sale of cash crops, making this type the most market oriented. Types 3 and 4 were characterized by moderate levels of resource endowment. Type 3 comprised labour-intensive medium-to large farms dominated by maize and legumes. Livestock consisted mostly of small ruminants. Type 4 was the largest group and it exhibited structurally similar farming systems to those of Type 3, except on a smaller scale; making it more land and labour-limited. Types 5 and 6 encompassed low resource endowed farm households. Type 5 was particularly land-constrained, characterized by small farms dedicated to maize production for household consumption and almost no income-generating off/non-farm activities. Type 6 was the smallest group and represented the most poorly-endowed households, with small herds dominated by poultry, and income procured from livestock sales combined with low-paid off-farm activities. Finally, the types were validated by a local expert (former agricultural extension officer for the Northern Region). Additional details on the multivariate analysis and resulting typology are provided in Kuivanen et al. (2016a).

3.2.4 Procedure to construct the participatory typology

Towards the end of the cropping season in September 2014, the three Africa RISING intervention communities included in the 2013 baseline survey for the Northern Region were approached for collaborative formulation of a participatory typology of farming systems. Inspired by the Participatory Learning and Action approach for learning about- and engaging with communities (Lynam et al., 2007; Pretty et al., 1995; Salomon, M.L.; Engel, 1997) and working closely with a native-speaker translator who also possessed an intimate knowledge of local farming systems, a procedure was developed comprising four mutually supporting steps, referred to here as: 'introduction', 'simple exploration', 'complex exploration' and 'convergence'. The procedure was piloted in two non-survey villages before being adjusted and executed in each of the three target communities in turn. The steps are summarised below.

Step 1: Introduction

An introductory meeting in each community served as a platform to present the research objectives and request the cooperation of the chief and villagers. With the help of a translator, facilitator and other community members, these meetings were also used to identify 10 'key informants' (henceforth referred to as 'farmers') per village who represented a cross-section of the population in terms of status, age, gender and ethnicity. These key informant farmers fulfilled the necessary condition of possessing ''common knowledge'' (knowledge shared by the members of communities) of local farming systems (Barahona and Levy, 2005). To gain a preliminary understanding of the study area, focus group discussions were held with the 10 farmers, where the history, demographic makeup, social structure, production, off/non-farm activities, land tenure system and public services of the communities were discussed (*cf.* Table 3.1 for a partial summary).

Step 2: Simple exploration

Participatory resource mapping was conducted with the farmers to reveal the community's perception of how physical space and resources were used. The maps provided a valuable visual representation of socio-cultural, institutional and natural features such as sacred sites, school buildings, water bodies, livestock enclosures and arable fields. In addition, the mapping activity stimulated reflection and discussion around the link between resources in the community and the farmers as resource users. The exercise served as a primer for the following step.

Step 3: Complex exploration

The different types of farming systems that exist in the communities were identified from an emic perspective. This entailed breaking down the concept of 'farming system' into its more tangible sub-components (*e.g*. household, cropping activities, livestock). The first activity thus involved delineation of categories of difference in an open brainstorming session with all 10 key informants, guided by idiomatic 'can-openers' (Gotschi et al., 2009) such as: ‘We look at the fingers on our hands and see that each one is different. As the fingers on our hands are different; so the [farms/ farmers/ crops *etc.*] of [Botingli/ Kpalung/ Tingoli] are different. What are the differences that you see amongst yourselves?’ (translated from the vernacular). The differentiating criteria that emerged from this were recorded on a flipchart and then used in a sequential manner, first classifying farming systems according to the most salient criterion/criteria and then subdividing classes on the basis of other relevant criteria. The discussion was facilitated so that a useable set of categories were agreed upon.

Next, a commonly agreed-upon symbol which captured a representative feature of each category was assigned to these identified ‘farm types’ (*cf.* Table 3.3). Following this, the characteristics of each farm type were expounded. Additional farmer-defined secondary criteria were recorded in a matrix and where possible, for each identified criterion the different type-specific levels and quantitative ranges were obtained (*cf.* Table 3.4). For the purposes of comparison with the statistical types, farmers were also asked to describe the farm types in terms of additional criteria according to a checklist based on Table 3.2 (*cf.* Annex 3 for detailed descriptions of the types). The final activity involved assigning the 80 farms included in the baseline survey to the identified types. Cards were labelled with the name of the reference person of each sampled household (typically the male household head) and given to the farmers to classify one by one by placing them in the appropriate pile on the matrix. The farm types, their prevalence in the communities and relationships to each other were discussed.

Step 4: Convergence

A transect walk was chosen with farmers to traverse the main land use systems of the village. This enabled a visit to representative farms of selected farm types identified in step 3, and cross-checking of some criteria by direct observation (*e.g.* dwelling type, *cf.* Table 3.4).

3.2.5 Comparison of the typologies

In order to assess the (non-)complementarity of the positivist (statistical) - and folk (participatory) approach, we first compared the variables resulting from the PCA and differentiating criteria determined collaboratively with farmers. We then calculated the overlap between the farm household classifications as a measure of the (dis)similarity between two given groupings (Martin et al., 2001).

3.3. Results and discussion

3.3.1. Comparison of the statistical and participatory typology

3.3.1.1. Participatory typology

Capturing farm diversity through the analysis of typologies is a key step in the design of agricultural development strategies, interventions and policies that are tailored to the local context. Combining local expert and scientific knowledge in typology construction can lead to a more comprehensive understanding of the multiple dimensions of farming systems (Righi et al., 2011). In this study we compared two different approaches to the characterization of smallholder farming system diversity in Northern Ghana; a positivist (statistical) typology described in Kuivanen et al. (2016a) and a folk (participatory) typology. An important result of the participatory typology was the adoption by farmers of the 'individual' (*i.e.* plot holder or farmer) as the unit of analysis. On the other hand, in the statistical typology the unit of analysis was the 'farm household'. Nevertheless, for the sake of simplicity, we continue to refer to the statistical- and participatory types as 'farm types'.

Table 3.3. The main characteristics of the five farm types determined using participatory methods (HRE: High resource endowed; MRE: Medium resource endowed; LRE: Low resource endowed; SRC: Severely resource constrained).

Type	Symbol[a]	Main characteristics	Type prevalence in the communities[b]	Proportion in the survey
A	 'Household heads are always happy and smiling'	*Pukparkara* ('Big farmers, men'): HRE (large farm size), market-orientation	++	8%
B	 Fist and outstretched hand indicate that 'what these farmers have is not enough, they need more to be self-sufficient'	*Pukparsagsa* ('Medium farmers, men'): MRE (medium farm size), variable production orientation	++++	52%
C	 The hoe symbolizes that the farmers 'cannot afford to hire the services of a tractor'	*Pukparbihi* ('Small farmers, men'): LRE (small farm size), subsistence orientation	+++	40%
D	 The cooking pot and cutlass are 'tools used by women'	*Pagba pubihi* ('Small farmers, women & children'): LRE/ SRC (small farm size), market orientation	+++++	0%
E	 The ear suggests that the 'farm-less always listen out for work opportunities'	*Suhukpion* ('Farm-less, men'): work on other farms as hired labour	+	0%

[a]Examples of farm type symbols; [b]Relative proportion of each type: + (very small); ++ (small); +++ (medium); ++++ (large); +++++ (very large).

***Table 3.4**. Summary of the main characteristics of the (S) statistical typology (resulting from PCA) and (P) participatory typology (farmer-defined).*

Variables	S	P	Statistical typology						Participatory typology				
			Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type A	Type B	Type C	Type D	Type E
Demographic													
Household size and composition	✓	✓	Large: 17-34 persons	Medium:9-24 persons	Medium: 9-30 persons	Variable: 4-37 persons	Variable: 6-33 persons	Small: 6-16 persons	Large, extended, polygamous	Variable: 6-30 persons	Variable: 2-10 persons	N/A	Single person
Age, gender, status		✓							Older men, incl. household heads	Older men incl. household heads and male youth	Older men incl. household heads and male youth	Women and children	Men of variable age
Labour													
Total labour input	✓		Medium	High	Highest	Low	Low	Lowest					
Family & exchange/ Hired labour	✓		Mostly family	Mostly family	Medium share of hired labour	Largest share of hired labour	Medium share of hired labour	Medium share of hired labour					
Cropping system													
Farm size (average)	✓	✓	Medium (3.6 ha)	Largest (6.3 ha)	Large (5.2 ha)	Medium (3.5 ha)	Smallest (2.5 ha)	Small (2.6 ha)	Large > 4 ha	Medium 0.8-4 ha	Small 0.4-2 ha	Smallest 0.1-0.4 ha	Farm-less 0 ha
Land use and production orientation	✓	✓	Maize based	Legume and maize dominated	Legume and maize dominated	Legume and maize dominated	Maize dominated	Maize dominated	Mainly cash crops, high yields	Food crops and cash crops	Mainly food crops	Mainly cash crops, intercrop low yields	N/A
Inputs and equipment		✓							Improved seed, fertilizers + tractor	Improved seed, fertilizers + animal traction	Fertilizer +Hoe and cutlass	Hoe and cutlass	N/A
Post-harvest storage		✓							Large grain huts	Medium grain bins	Bags	Bags and pots	N/A
Self-sufficiency		✓							Yes	Variable	No	N/A	No
Livestock													

Herd size and main composition	✓		Largest herd (cattle)	Large herd (cattle)	Medium herd (small ruminants)	Small herd (small ruminants)	Medium herd (small ruminants)	Smallest herd (poultry)					
Socio-economic													
Main income sources	✓		Non-farm income	Crop sales	Crop and livestock sales	Crop sales	Crop and livestock sales	Off-farm income and livestock sales					
Dwelling type		✓							Zinc roofed	Variable	Thatch roofed	N/A	N/A
Income investment		✓							Motorbike, tractor, livestock, business	Services (tractor and transport), livestock	Bicycle, food, inputs	Household necessities, inputs, education	Variable
Personal characteristics		✓							Wear good shoes, eat meat, happy	Dress decently and children are healthy	Parents quarrel a lot, children look hungry	Variable	Lazy, fast living, big spender

Delineation of a participatory typology of farming systems in collaboration with local farmers resulted in three community-specific typologies comprising five farm types in Botingli, three types in Kpalung and five types in Tingoli. In all communities, the most salient differentiating criterion was that of 'farm size'. The four most frequently identified criteria were 'farm size', 'gender' (of plot holder), 'age' (of plot holder) and 'income investment' (Table 3.4). This enabled synthesis of the community-specific typologies into one global typology for the case-study area comprising five farm types, each represented by selected farmer-defined symbols (Table 3.3). Several other secondary criteria were identified and these are summarised in Table 3.4.

Characterization of the resulting farm types revealed that Types A-C exhibited a trend similar to that demonstrated in the statistical typology: the gradient in farm size (representing resource endowment) tended to be positively related to high-value crop production and asset ownership; considered to be proxies for wealth (Chapoto et al., 2013; Negash and Niehof, 2004; Tittonell et al., 2010). The farmers' estimates of the relative proportions of these types in the study communities seemed to indicate that moderately endowed Type B constituted the second-largest group followed by resource-constrained Type C, while well-endowed Type A farmers represented only a small minority. Types D and E were unique to the participatory typology. Type D comprised the wives and young children of the farmers belonging to Types A-C and therefore constituted the largest cluster in the communities. Type E, on the other hand, constituted the smallest cluster in the communities and comprised 'farm-less' men. In the strictest sense, the latter group should not be categorized as a farm type as its members owned no farm and their source of livelihood was mainly off-farm. However, they are included in the result due to their being recognized by the farmers as a distinct group of (deviant) individuals/ farmers that nevertheless form part of the community (Table 3.3; Annex 3).

3.3.1.2 Comparison of variables

Different variables/criteria were selected for statistical- and participatory clustering. While the PCA results used for clustering in the statistical typology tried to merge variables into a smaller number of dimensions, so that the clustering reflected an analysis of combined explanatory variables; in the participatory typology the criteria were used in a sequential manner first classifying farmers according to farm size and then subdividing classes on the basis of other relevant criteria. Some variables that had discriminatory value in the statistical typology were weakly represented in or absent from the participatory typology and *vice versa* (Table 3.4). Some of the variables had similar descriptive names, but their underlying meaning diverged due to interpretation as well as cultural differences, while others had different descriptive names, yet their underlying meaning converged. In the following paragraphs, the selection and representation of variables employed in the construction of the typologies is analysed.

Demographic

The variable of 'household size' was used in both typologies and proved to be a strong descriptor of wealthier Type 1 and Type A, associated with larger households (Table 3.4). The demographic criteria of 'household composition', 'gender', 'status' and 'age' (of plot holder) were included in the participatory typology, but not considered for delineation of statistical types. This is mostly due to the different units of analysis *i.e.* the farm household as a whole for the statistical typology *vs*. individual farmers for the participatory typology. In the participatory group discussions, farmers viewed 'gender' as a key determinant of farm size and differentiated between larger farms owned by men and smaller farms cultivated by women. In addition, the participatory process revealed that 'status' and 'age' were positively related and also exhibited strong discriminatory power: farmers distinguished older men (*e.g.* senior household heads), younger men and children. Finally, 'household composition' described the make-up of the domestic unit within which farmers were embedded. Distinctions were made between smaller nuclear, larger extended, polygamous and non-polygamous farm households.

Labour

Labour was an influential factor in the statistical typology, in particular the 'total labour input' variable rather than the 'hired labour ratio' variable (Fig. 2.2A; Table 3.4). Labour was not directly identified by farmers as a differentiating criterion, but was indirectly alluded to via the analogous criteria of 'agricultural equipment' and 'farm size'. 'Agricultural equipment' differentiated between farmers who used hoes and cutlasses, draft animals and tractors, thus constituting a rough indicator of the labour input associated with manual *vs.* mechanized land preparation and other tillage practices. Secondly, the delineation of farm types based primarily on the criterion of 'farm size' resulted in a 'farm-less' category of men who worked exclusively for wages off-farm and in non-agricultural activities (*cf.* Annex 3). This category in itself was therefore indicative of a certain type of labour(er) that existed in the communities, as distinct from household labour, exchange labour and farmers who occasionally hired themselves out as seasonal labour.

Cropping system

The farm or *puu* was defined as the area of inherited land that a farmer cultivated (uncultivated areas were not considered to be part of the farm) (Iddrisu Baba Mohammed, 2014: *pers*. *comm*.). It was described by farmers as the cornerstone of Dagomba livelihood; 'without a farm, you are nothing'. Furthermore, according to farmers; the difference in farm sizes was the most defining feature of the farm systems in the communities (Table 3.3). It was explained that the size of the plot allocated to an individual depended on a number of factors such as access to resources (*e.g.* family- and market labour), gender of ownership (women and children were restricted to smaller farms) and the physical capabilities of farmers (related to age and health status). Interestingly, the strong discriminatory power of 'farm size' in the participatory typology was not reflected in the statistical typology, where the corresponding variable of 'cropped land area' only displayed a relatively weak correlation with PC 2 (Fig. 2.2A). Furthermore, the participatory clustering process revealed that resource endowment, specifically farm size, was positively related to wealth-indicating socio-economic criteria such as 'income investment' and 'dwelling type'. This is not surprising, considering that expansion of the farm area is often the principal means of increasing yields (and saleable output) in low-input, land-constrained systems (Negash and Niehof, 2004; Ohene-Yankyera, 2004).

Although both typologies included various criteria to describe the cropping system, it seems that this dimension was more important for differentiating between farm types in the participatory typology. In the statistical typology, the quantitative variables of 'maize ratio', 'legume ratio' and 'percentage crop sales' (Table 3.2) corresponded to the qualitative 'crop types' and 'production orientation' criteria selected for participatory classification (summarised under 'Land use and production orientation' in Table 3.4). 'Crop types' described the different crops (food- and cash) cultivated on a farm and their estimated yields, while 'production orientation' provided some clues about on-farm income sources by differentiating between the proportions of cash crops and food crops cultivated by farmers. In addition to these, the participatory typology also included criteria such as 'cropping practices' (sole cropping, mixed cropping or inter-cropping; summarised under 'land use and production orientation' in Table 3.4), 'agricultural equipment' (use of tractors, animals, hoes or cutlasses for tillage), 'agricultural inputs' (access to- and usage of mineral fertilizer, agro-chemicals and improved seed) and 'post-harvest storage' (traditional grain bins *vs.* pots or sacks). It was explained that farmers who had access to inputs were able to increase farm productivity, thus distinguishing them from those with more limited access, and thus lower yields.

Provision of food for the family was the responsibility of the household head, and food that could not be sourced on-farm had to be purchased (Al-Hassan and Poulton, 2009; Oppong, 1967). Therefore, in line with

Ohene-Yankyera (2004), we consider farm size to be critical for household food security. By extension, it is argued that the level of seasonal food self-sufficiency enjoyed by a farm household is an important indicator of farm size, thus justifying the inclusion of 'self-sufficiency' as a differentiating criterion by farmers. Possibly due to farmer misestimation of seasonal food availability during survey data collection, no clear relationship between food self-sufficiency and the different farm types was found in the statistical typology (Kuivanen et al., 2016a).

Livestock

While livestock features were key descriptors in the statistical typology, during the participatory process farmers did not include animal numbers, types or husbandry practices in their criteria for discriminating between farm types in any of the communities (Table 3.4). This apparent omission of livestock-related criteria may be partly explained by the traditional centrality of crop farming to Dagomba cultural identity (Iddrisu Baba Mohammed, 2014: *pers*. *comm*.). Although livestock ownership has historically played a role in Dagomba livelihood strategies; manure exchange- and herding arrangements with Fulani were common until recent times (Bellwood-Howard, 2012). Nevertheless, the animal component was acknowledged in the descriptive phase of participatory typology formulation, where farmers were asked to further elaborate on the characteristics of each identified type. This revealed a positive relationship between farm size and livestock ownership: apart from animals acquired through inheritance, ownership of livestock was dependent on purchase using income generated from surplus crop product sales. Similarly to the statistical typology; herd size and composition varied between the types (*cf.* Annex 3), with cattle being an especially good descriptor of farmer endowment (Laube, 2007; Marchetta, 2013).

Socio-economic

Livelihood strategies were described in both typologies using income-related criteria (Fig. 2.2B, C and D; Table 3.4). In the statistical typology, variables were included that differentiated the income sources among households (Table 3.1). In the participatory typology, discrimination between food-and cash crops (represented by the 'crop types' and 'production orientation' variables) provided an indirect indication of the diversification strategies among farmers; with those oriented mainly towards cash crop cultivation assumed to derive more income from crop sales. Conversely, because livestock acted as a store of value and were rarely sold except in times of extreme shock such as crop failure or famine (Laube, 2007), such farmers were assumed to be less likely to depend on the sale of livestock for income. The omission of farmer-defined criteria related to off/non-farm activities may be partly attributed to the socio-cultural emphasis placed on agriculture as well as the relative dearth of non-farm opportunities in Ghana's Northern Region (Chamberlin, 2008). Average dependence on off/non-farm income sources was found to be quite low among the surveyed farmers who seemed to rely more on their farm enterprise for income (Table 3.2).

Unequal levels of farmer financial endowment were represented by the unique socio-economic criteria of 'income investment', 'dwelling type' and 'personal characteristics' in the participatory typology. 'Income investment' described differential levels of farmer asset ownership (*e.g.* tractors, motorcycles and livestock) as a result of investment choices. In the statistical typology, farmer wealth investment was represented by the variables associated with 'livestock ownership' (Table 3.2). 'Dwelling type' described physical differences in household compound structures by discriminating between traditional huts of mud-brick and thatch construction, and modern concrete and zinc structures. Modern compounds were considered to be more expensive to build and associated with well-endowed farmers (Pellow, 2011). Finally, 'personal characteristics' described the highly subjective, more intangible perceived differences in signifiers of health, personality and clothing style of farmers, which were understood to be positively related to wealth.

3.3.1.3 Classificatory overlap

The third step in the procedure for constructing the participatory typology ('complex exploration') required farmers to position the head of each household included in the baseline survey within the identified system of farm types. This facilitated later comparison of the types and allowed for an analysis of the overlap, *i.e.* (dis)similarity between assignments to types when comparing the statistical and participatory classifications.

First, we reorganized the survey data into the participatory farm types, and computed mean values of selected variables for each type in the statistical and participatory typologies. Comparison of these 'mean profiles' showed some similarity in terms of the inherent structure of the types: the means of selected variables for the participatory Types A, B and C were found to roughly correspond to the means of the same variables for the associated statistical types. For example, type-specific mean values for the variables of cropped land area, herd size and household size tended to be lowest for resource-constrained Types 5, 6 and Type C, and highest for the wealthier Types 1, 2 and Type A (Fig. 3.1A-C). This seems to imply that the general trends captured by the statistical typology were validated by the participatory typology.

Nevertheless, subsequent examination of the distribution of the participatory farm types across the statistical farm types revealed limited overlap when comparing the two typologies, with medium-endowed, statistical Type 4 tending to englobe almost half of the surveyed farm households (Table 3.2) and three of the participatory types (Fig. 3.1D). More specifically; the households associated with the small share of wealthier household heads assigned to Type A in the participatory typology (Table 3.3) were not distributed within the corresponding well-endowed statistical Types 1 and 2, as would have been expected. However, they were to be found in the medium-endowed Types 3 and 4 as well as amongst statistical outliers (Fig. 3.1D).

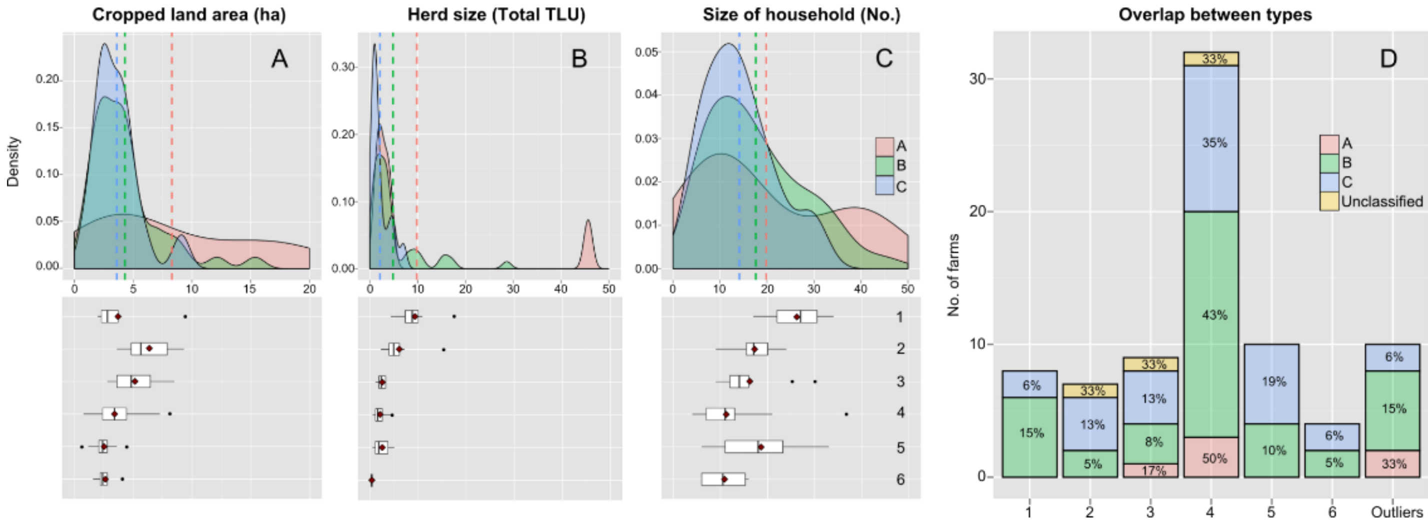


Figure 3.1. *Participatory (n=77 farms including 3 unclassified farms) and statistical (n=70 farms including 10 outliers) typology overlap: kernel density curves per participatory farm type (dashed lines representing the group means) and boxplots per statistical farm types (coloured point representing the group means) for the variables of cropped land area (A), herd size (B) and household size (C); and histogram showing the distribution of the participatory types across the statistical types (D).*

More than half of the sampled household heads were identified by farmers as belonging to moderately-endowed Type B (Table 3.3); yet only 43% of the associated households were statistically classified as medium-endowed Type 4, while the rest were distributed amongst the other five statistical types (Fig. 3.1D). Furthermore, farmers assigned 40% of the sampled heads to poorly-endowed Type C (Table 3.3). However, only 25% of these were statistically determined as representing the corresponding resource-poor households of Types 5 and 6 (the rest were assigned to the wealthier Types 1-4). Finally, and perhaps most obviously, as the reference system of the survey included household heads who were invariably male farmers, none were classified in the unique categories of female/children (Type D) and farm-less (Type E) in the participatory typology (Table 3.3).

3.3.2 (Dis)similarity between the farms types

Although there are numerous advantages of using farmer knowledge in scientific research, discrepancies between farmer and researcher observations may occur (Asten et al., 2009). The overlap between the two typologies was limited due to a range of factors: differences in the grouping approach and units of analysis, inaccuracies in the data, changes that occurred between the two data collection efforts, misidentification of household heads for classification in the participatory typology and deletion of farms as outliers during statistical analysis. These are further elaborated in the following paragraphs.

Approach and units of analysis

The grouping approach was fundamentally different for the statistical- and the participatory typology and this had important implications for the resulting farm types. The positivist approach of the statistical typology required measurable, quantitative data which was obtained through a structured survey; leaving intangible dimensions such as social relationships, personal characteristics of farmers *etc*. only partially represented (Randall and Coast, 2015). By contrast, the folk approach of the participatory typology enabled face-to-face contact and open dialogue with the farmers themselves, and the participatory farm types emerged from a host of small questions (bottom-up) rather than starting with a focus on the system itself (top-down). This emic approach yielded information that is difficult to capture in standard surveys; as illustrated by the socio-culturally-relevant symbols assigned to each type which served to summarise the farmers' perspectives and also provide insight into the kind of conceptual framework farmers use to organize their realities (McKinney, 1969) (Table 3.3).

Furthermore, the different units of analysis (household *vs.* individual farmer) on the basis of which the typologies were constructed contributed to mismatch between the classifications: in the statistical typology, a given household was allocated to a farm type on the basis of information provided by the head himself; whereas in the participatory typology the surveyed household heads were assigned to farm types based on the perceptions of key informants. While surveys have the practical advantage of aggregating data at household level (through the lens of a single reference person), they may lead to a poor representation of reality, particularly in the context of more complex, extended and/or polygamous domestic units such as those commonly found in the study area (Budlender, 2003; Randall and Coast, 2015). Thus, by not interviewing multiple respondents within the household, the survey rendered certain categories of people less visible; such as those whose main occupations and income sources were off the farm, and women and children (*cf.* Doss et al. (Doss et al., 2015)). For example: the wife and children associated with a resource-rich, male head would appear to be a wealthy household and classed as Type 1 in the statistical typology. The participatory typology, on the other hand, would classify the women and children as relatively resource-poor Type D. The latter approach thus provided a more nuanced differentiation, making allowance for the co-existence of multiple farm types in a single farm household and acknowledging potentially important target groups for the R4D project that were not included in the statistical typology, such as female farmers (Type D) and 'farm-less' men (Type E).

Nevertheless, as evidenced by a common trend in the gradient of resource endowment among types, the typologies also shared some aspects of inherent structure (*i.e.* similar mean profiles; *cf.* Section 3.3.1.3). This complementarity between the types may be explained by the fact that the units of analysis, while telling different stories, were not divorced from each other: an individual (farmer) is usually embedded in a household.

Data inaccuracy

Data collected in the survey did not fully reflect reality for other reasons which include: misunderstanding by farmers of questions posed by enumerators, the difficulty of estimating quantitative variables (*e.g.* farm sizes, livestock numbers, age *etc.*), the spatially dislocated (fragmentation of farms and animal herds) yet socially interconnected context, local socio-cultural norms and the perceived social distance between farmers and enumerators. For example, farmers assigned a household defined as moderately endowed (Type 3) in the statistical typology to a wealthier group (Type A) in the participatory typology. It was explained that the household head in question had inherited a medium-sized farm but had enlarged the area through land borrowed from neighbours. However, only the part of the farm that had been acquired through inheritance had been recorded in the survey. Similarly, it was claimed that the same farmer possessed a sizeable herd of cattle, despite this not being apparent from the survey. This was attributed to the fact that his cattle were often tended to by relatives outside of the community. Related to the previous point, farmers explained that cattle were commonly inherited by male members of the descent group and herds were considered to be the joint property of the inheritors, making it improper for any single inheritor to 'claim' sole ownership. The tendency for farmers to downplay cattle numbers was also linked to the lingering legacy of a historical taxation system which penalized farmers with large animal herds (Iddrisu Baba Mohammed, 2014: *pers. comm*.).

Moreover, Dagomba society is hierarchical, and deference towards those of higher rank or status is expected (Oppong, 1967). During participatory classification; cultural and social (power) issues tended to distort the assessment of household heads, some of whom were considered to be of high social standing, such as the councillors to the chief (*e.g*. *tamalnaa*, *wulana*, *zoonaa*), the sub chief (*zakyurinaa*), community elders, religious leaders, teachers and ranked members of the traditional warrior class. It is possible that farmers may have felt obliged to show their respect for these individuals by assigning them to 'superior' types, despite the information collected in the survey revealing otherwise.

Finally, the Dagomba saying; '*ashili nyedoo'* ('secrets make a man') illustrates what appeared to be a general reluctance among community members to reveal personal information. This seemed to hold particularly true when dealing with 'outsiders'. Farmers explained that while they were distrustful of the intentions of strangers perceived as *karachi* (educated), they were also aware of the possibility of achieving (short-term) benefits from such interactions: 'If I say I am fine, then I won't be helped'. This may have led to cases of deliberate misrepresentation of farm household situations during both survey interviews and participatory discussions.

Structural changes

Typologies, unless regularly updated, do not reflect the dynamic nature of farming systems or the movement of types in time (Iraizoz et al., 2007; Landais, 1998). Therefore, changes to farm structure (*e.g.* farm size or herd size*)* that had occurred in the communities in the year between survey data collection and participatory analysis with farmers, may have contributed to classification discrepancies. In an example that highlights the importance of the socio-historical context of farm performance for determining type membership; a household classified as moderately endowed (Type 4) in the statistical typology was assigned to well-endowed Type A in the participatory typology. The farmers justified this decision by explaining that the household head in question was known to consistently cultivate large tracts of land, but that at the time of the survey had been forced to temporarily downsize his cropped area as a coping strategy in the face of unexpected crop failure.

Farmers emphasized this fluidity in discussions during the participatory sessions. It was remarked, for instance, that moderately-endowed Type B continuously absorbed farmers into its ranks and that the rate of 'regression' from resource-endowed Type A to moderately-endowed Type B was higher than the rate of 'progression' from resource-constrained Type C to Type B. Indeed, Type B and Type 4 encompassed the largest share of surveyed household (heads) in the participatory- and statistical typology respectively, many of which appeared to be 'borderline cases' that did not fit neatly into the more narrowly defined extreme types. This heterogeneity may partially account for the dispersion of Type B farms across the statistically defined categories and the apparent encapsulation of all the participatory types in Type 4 (Fig. 3.1).

Misidentification of farm households

Incorrect identification of the sampled household heads by farmers during 'complex exploration' (step 3) may have resulted in misclassified cases. Households were assigned to participatory types on the basis of the officially recorded, full names of their heads. This turned out to be problematic; as some household heads shared the same name, or were known to members of the community only by their nickname. This was partly addressed by referring to secondary identifiers recorded in the survey, such as tractor or television ownership. On occasion, farmers retracted their classification decisions on the premise that the household head had been misidentified. In total, 3 households remained unclassified due to doubts concerning their identity.

Data screening

To avoid distortions in the multivariate analysis, outliers were deleted from the survey dataset. Results of the overlap analysis seemed to suggest that some of the wealthiest farm households were expunged in the data screening process of statistical analysis as outlying observations, for example due to herd sizes which surpassed the researcher-defined cut-off point of 20 TLU. For the most part, farmers assigned the household heads associated with these statistical outliers to well-endowed Type A and moderately-endowed Type B. Interestingly, it was noted that households with herd sizes larger than the attributed threshold also exhibited farms of well above average size and were situated in the community of Kpalung, where land and the services of Fulani herdsmen were reported to be more readily available than in the communities of Botingli or Tingoli (Table 3.1).

3.4. Conclusions

This research was carried out in response to a call for the design and implementation of situated agricultural development interventions and policies that take into account local farming system diversity. We compared two contrasting approaches to the characterization of farming systems in three intervention communities of an active R4D project in Northern Ghana: a quantitative, statistical typology based on household-level survey data and multivariate analysis, and a qualitative participatory typology based on group sessions and participatory activities with selected key informants. The statistical typology provided a general impression of the main structural- and functional features underpinning farm variation, while the participatory typology resulted in a more nuanced analysis of diversity at the level of individual plot holders (farmers).

Our study showed dissimilarities in both type delineation and the resulting systems of types between the approaches. In the statistical typology the unit of analysis was the ‘farm household’, and multivariate analysis led to the identification of six farm types. Types 1 and 2 were the wealthiest, Types 3 and 4 were characterized by moderate levels of resource endowment, and Types 5 and 6 encompassed poorly endowed farm households. Formulation of a participatory typology resulted in five types, based on the ‘individual’ as the adopted unit of analysis. Types A-C exhibited similar trends to those found in the statistical typology; the gradient in endowment among these three types tending to be positively correlated with wealth indicators such as high-value crop production and asset ownership. Types D and E, on the other hand, were distinctive to the participatory typology and comprised the wives and young children of the farmers assigned to Types A-C and ‘farm-less’ men, respectively. Furthermore, different variables were selected for statistical and participatory clustering. While the PCA results used for clustering in the statistical typology tried to merge variables into a smaller number of dimensions, so that the clustering reflected an analysis of combined explanatory variables; in the participatory typology the criteria were used in a sequential manner first classifying farmers according to farm size and then subdividing classes on the basis of other relevant criteria. Finally, analysis of the overlap between assignment of surveyed household (heads) to types when comparing the statistical and participatory classifications revealed discrepancies. These were attributed to a number of factors such as differences in the approach and units of analysis, inaccuracies in the data due to interpretation and socio-cultural (power) issues, changes that occurred between the two data collection efforts, misidentification of household heads for classification in the participatory typology and deletion of farms as outliers during statistical analysis.

We conclude that while the use of statistical techniques warrant objectivity and reproducibility in the analysis, the complexity of data collection and representation of the local reality might limit their effectiveness in selection of farms and of innovation targeting and out-scaling in R4D projects. In addition, while participatory typologies offer a more contextualized representation of heterogeneity, their accuracy can still be compromised by socio-cultural constraints, epistemological differences between local and scientific knowledge domains, as well as the perceived social distance between farmers and researchers, for example. For both statistical and participatory typology approaches, the dynamic nature of farms and households, with changes that can occur either gradually or as discrete events, should be addressed more explicitly to remain relevant and effective in R4D projects. Therefore, neither the reliance on local experts as information sources, nor structured surveys are sufficient for the comprehensive understanding and analysis of complex and diverse farming systems by themselves. We concur with recommendations made elsewhere to make effective use of the advantages offered by both approaches by integrating them (Alary et al., 2002; Den Biggelaar and Gold, 1995; Pacini et al., 2014; Righi et al., 2011). Although engaging in participatory work takes time and effort; if employed prior to statistical approaches, the rich insights it provides may help to focus scarce resources on relevant activities and enhance the quality of research (for example in the selection of more appropriate variables to use in multivariate analysis, improved survey design, *etc*.). Using qualitative methods in addition to quantitative tools also provides a solution for working with incomplete available data, while ensuring that contrasting but complementary information from both emic and etic perspectives are included in the final output.

Chapter 4

4. What technology package works for whom?

Based on:

Michalscheck, M., Groot, J.C.J., Kotu, B., Hoeschle-Zeledon, I., Kuivanen, K., Descheemaeker, K., Tittonell, P., 2018. Model results versus farmer realities. Operationalizing diversity within and among smallholder farm systems for a nuanced impact assessment of technology packages. Agric. Syst. 162, 164–178. https://doi.org/10.1016/j.agsy.2018.01.028

You may access the article online by scanning the QR-code with a mobile device.

Abstract

Agricultural production in Northern Ghana is dominated by smallholder farm systems, which are characterized by low inputs and low outputs, declining soil fertility, large yield gaps and limited adoption of agricultural technologies. There is an urgent need for alternative farm designs that are more productive, yet more sustainable. Technology packages for sustainable intensification are promoted by an R4D project in the Upper East, Upper West and Northern Regions of Ghana. In this paper, we analyse differences in perceived suitability, and modelled technical impact per technology package.

We used a locally validated framework to categorise farm systems diversity that considers both, the horizontal (between households) and vertical (within households) dimension of diversity. Farm households were classified along a gradient of resource endowment. We selected one representative farm per type and per region to assess and compare their socio-economic and environmental performance (farm profitability, labour and soil organic matter inputs) using the whole-farm model FarmDESIGN. We then used FarmDESIGN to assess the potential impact of five proposed technology packages and to explore promising alternative farm configurations. We discussed model assumptions and results with farmers, including alternative cropping patterns and trade-offs. We evaluated the packages with different household members using a weighted scoring technique, subsequently juxtaposing model results with farmer perceptions.

Large differences prevailed among and within farms per type and per region, with low resource endowed farms being projected to benefit most in relative and least in absolute terms from an adoption of the packages. Farmer feedback confirmed the accuracy of alternative farm configurations, as determined by the model. However, the feedback also revealed that the most profitable farm designs would be hard to attain in reality, particularly for members of low and medium resource endowed households, due to high initial investment costs. Within households, women were more positive about the packages than men, since men heavily penalized extra costs and labour, translating into a greater congruence of model results with the male evaluation. We discuss the importance of distinguishing between technical (technology i.e. purchased tools and inputs) and managerial (techniques *e.g.* row planting) package components. We conclude that operationalizing inter- and intra-household diversity is a fundamental step in identifying sensible solutions for the challenges smallholder farm systems face in Northern Ghana.

Keywords: ex-ante impact assessment; Northern Ghana; technology adoption; typologies; whole-farm model FarmDESIGN

4.1. Introduction

Smallholder farm systems produce about 80% of the food consumed in Africa and Asia (UNEP, 2013), they supply the bulk of rural labour (Collier and Dercon, 2009; FAO, 2004) and they typically maintain a high regional agro-biological diversity (Kull et al., 2013; Zimmerer, 2014). However, their agricultural productivity is usually low and under threat of further deterioration due to their remoteness, lack of capital, inputs and information (Becx et al., 2012; FAO, 2011).

In Northern Ghana, smallholder farm systems face a variety of challenges related to low inputs and low outputs, declining soil fertility, post-harvest losses of about 20-50% as well as strong fluctuations in market prices (Affognon et al., 2015; Ellis-Jones et al., 2012; Osei-Owusu et al., 2013). Local productivity gaps in the main staple crops maize, sorghum and millet range from 80-90% (GYGA, 2016), suggesting a large potential for sustainable intensification (Pretty et al., 2011; Vanlauwe et al., 2014). Since agro-ecosystems are cybernetic systems that are strongly shaped to fulfil human objectives (Altieri et al., 2015; Tittonell, 2013), researchers need to team up with farmers in order to identify, discuss and implement alternative farm designs (Rodriguez and Sadras, 2011) that are more productive, yet more sustainable. Promoting sustainable intensification among smallholder farmers is the objective of the R4D (Research for Development) project Africa RISING (USAID, 2017). In Northern Ghana, Africa RISING conducted participatory on-farm trials *i.a.* for five technology packages that aim at an improved cultivation and a better integration of maize, cowpea and soybean within local farm systems (Kotu et al., 2016; Larbi et al., 2016a, 2016b). In this paper we investigate how different farms and farmers respond to the five project-proposed packages.

While a differentiation of farms (household types) is common in adoption studies (Cortez-Arriola et al., 2015; Singh et al., 2016; Tittonell et al., 2010), a differentiation between farmers within a household (individual household members) is not. Adoption studies typically treat farm households as unitary (Bensch et al., 2015; Tsiboe et al., 2016), referring to 'farmers and their farms' without specifying who, within a farm household, chose or was chosen to represent the farm (Dolinska and d'Aquino, 2016; Tittonell et al., 2010; Waithaka et al., 2006). At most, existing studies consider gender differences between (unrelated) male and female farmers (Bugri, 2008; Duncan, 2004; Emmanuel et al., 2016b; Jarawura, 2014; Khatri-Chhetri et al., 2017; Tetteh Anang, 2015): where survey samples include men and women it is unclear whether or not they are part of the same household. In Northern Ghana, agricultural fields and tasks are highly gender differentiated (Doss, 2002). While individual household members pursue individual production objectives and are the actual units of decision-making, they are tightly bound by joint resources and responsibilities at household level (Britwum and Akorsu, 2016; Pieper and Klein, 2007; Von Schlippe and Vienna, 2013). Our technology evaluation considers both diversity among and within farms. We chose one household per farm type and per community, consulting different members of the same household for their 'reality' *i.e.* their evaluation of each of the five technology packages.

At farm level, the adoption of a technology package typically affects multiple components, *e.g.* a change in crops affects fodder availability as well as the soil organic matter (SOM) balance. Despite the close-knit crop-livestock relationship in smallholder farm systems (Amankwah et al., 2012), most research on agricultural technology adoption in Ghana examines single technological innovations and impacts limited to the domain of action (Adjei-Nsiah et al., 2007a; MacCarthy et al., 2010; Nurudeen, 2011; Zakaria et al., 2014). An exception was Yiridoe et al. (2006), who used a whole-farm model, focusing on rice production in the Northern Region. The whole-farm perspective is indispensable to analyse the integrated character of mixed crop-livestock smallholder farms. We, too, used a whole-farm model to describe, explain and explore the performance of nine local farm systems, with and without the project-proposed technology packages. We used the bio-economic whole-farm model FarmDESIGN, which is a static model complemented by a multi-objective optimization algorithm (Groot et al., 2012). The algorithm is able to generate a large array of Pareto-optimal alternative solutions. Each solution constitutes a technical possibility to re-arrange the farm, allowing an exploration of concrete alternative farm configurations for sustainable intensification. Model-based farm descriptions are, however, only meaningful if farmers can relate to them. We therefore revisited all case-study households to discuss all model assumptions as well as the model-determined farm performance and the trends such as trade-offs between farm objectives.

By independently consulting various household members and by using the whole-farm model FarmDESIGN in a participatory fashion we assess the proposed technology packages in terms of their technical as well as their social viability, advancing to bridge the divide between the generation of theoretical farm designs and farmer realities (Dorward et al., 2003; Schindler et al., 2016; Whitfield et al., 2015).

The objective of this paper is to evaluate the five technology packages by comparing and matching a model-based impact assessment with the personal perspectives of individual household members for low, medium and high resource endowed farms (LRE, MRE and HRE) in the Upper East Region (UER), Upper West Region (UWR) and the Northern Region (NR) of Ghana. Per farm type and per region, we analyse (i) the current farm performance (Section 3.1), (ii) intra-household differences in the evaluation of the different technology packages (3.2), (iii) the impact of the different technologies on the socio-economic and environmental farm performance (3.3) and (iv) trade-offs in resource allocation within farms (3.4). Finally, we compare model results with farmer realities (3.5).

4.2. Methods

4.2.1. Case-study area

The study was conducted in one community in each of the three northern regions of Ghana: Duko located in the NR, Nyangua in the UER and Zanko in the UWR. Figure 4.1 displays the three regions, as well as our case-study locations. Duko and Zanko are part of the Guinea Savannah agro-ecology, spanning from Guinea-Bissau to Central-South Sudan, comprising most of northern Ghana (FAO, 2005). Nyangua is located in the Sudan Savannah agro-ecology, extending from Senegal to South Sudan, covering merely the north-eastern tip of Ghana (Germer and Sauerborn, 2005). Both agro-ecologies evince unimodal rainfall regimes with 1000-1200 mm and 900-1000 mm of rainfall per year, respectively. Temperatures range between 26 and 30°C.

In Northern Ghana livelihoods are based on small-scale, low input mixed crop-livestock agriculture. The main crops grown are cereals (maize, rice, sorghum, millet), legumes (groundnut, cowpea, soybean, Bambara bean, pigeon pea) and vegetables (roselle, okra, pepper). Depending on their level of resource endowment, farmers own cattle, donkeys, goats, sheep, pigs and poultry.

Local smallholder farm systems are family-farms, typically consisting of several partially independent units of production (Apusigah, 2009) each run by a different household member with a distinct production orientation. The partial independence is expressed in terms of 'own fields' for the different household members as assigned by the (customarily male) household head (HHH) or the community leader (the chief). Individuals live in so-called compounds, together with other nuclear or extended family members of the HHH (Al-Hassan and Poulton, 2009; Oppong, 1967).

While the male HHH cultivates cereals and tubers to ensure the family's food security, women farm different plots with vegetables and cash crops to achieve nutritional diversity (Doss, 2002) and to cover the children's basic school fees (Mohammed, 2015). If enough land is available also the younger household members cultivate their own plots, growing cash crops like rice to save capital for higher education or marriage. Also livestock ownership and responsibilities differ according to gender (Doss, 2002). Despite the distinct responsibilities and interests among the individual members, a household forms a strong unit of agricultural production, with tight interdependencies in decision-making, exchanging and sharing resources like tools, labour, capital and food from the various crop and livestock components of their farm (Pickbourn, 2011; UNU, 1994).

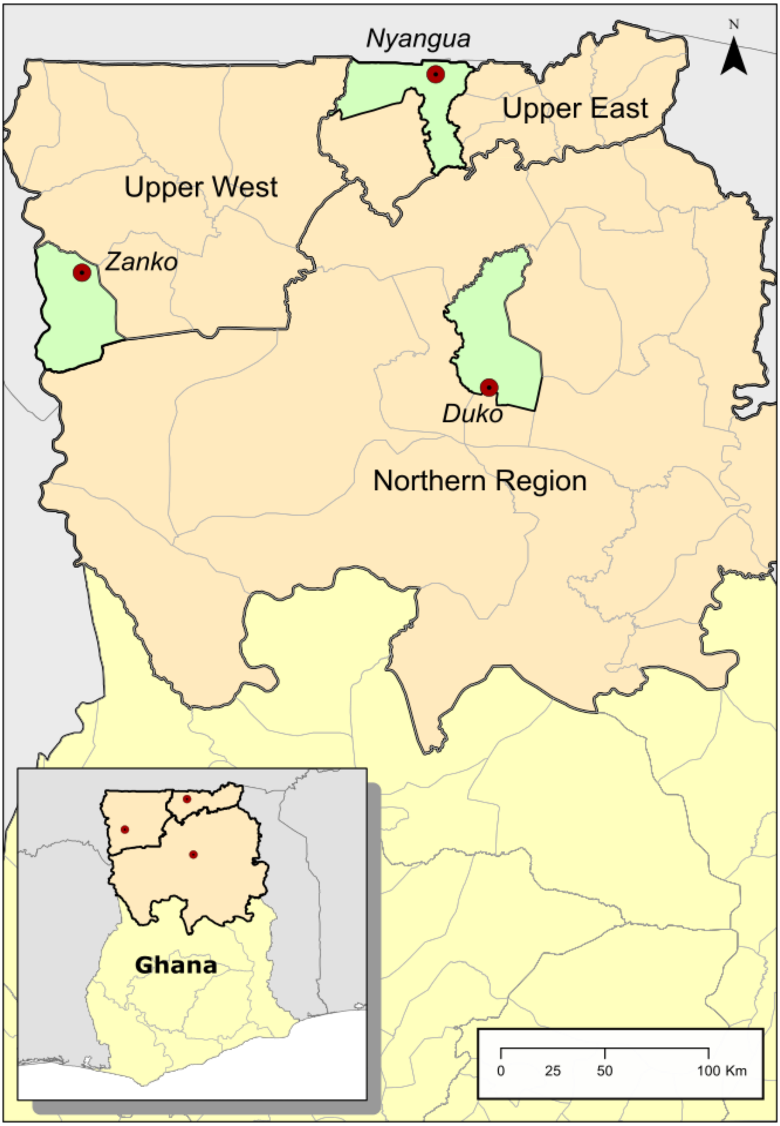
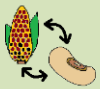


***Figure 4.1**. Map of Northern Ghana with case-study regions (orange) and communities (red dots).*

4.2.2. Technology packages

This study was conducted within the Africa RISING R4D program in Ghana. Our three case-study communities are intervention communities of the project. Since 2013, Africa RISING has operated so-called 'technology parks' in their intervention sites, which are community-based experimental stations with the aim to evaluate and demonstrate new technology packages, to provide hands-on training for farmers, to facilitate knowledge flow among farmers, to train students and to determine farmer preferences for technologies. The approach is similar to the 'farmer field schools' of the FAO (2016). In technology parks, each trial is associated to a 'control field' where farmers grow the same crops in a traditional manner. Selected farmers also run trials on their own fields: baby trials (15x15 m^2) or upscaled trials (0.405 ha), for which they receive instructions, advice and inputs from AR. We confined our technology evaluation to the currently implemented three technology packages (P1 to P3) at baby trial stage and two packages (P4 and P5) at upscaled stage ensuring that farmers were able to give feedback based on substantial own experience. Table 4.1 provides a description of each technology package and the assumed changes per hectare (inputs, yield, and labour) as compared to the respective traditional practices. The assumptions on inputs and yield increases for P1-P3 were based on agronomic trial data as published by Africa RISING (Kotu et al., 2016; Larbi et al., 2016a, 2016b). Due to the long-term-nature of benefits for P4 and P5, respective assumptions on yield increases were based on literature from West Africa (Dakora and Keya, 1997; Dakora et al., 1987; Horst and Hardter, 1994), choosing the most conservative figure (50%). The assumptions on labour increases and costs for the different package components of P1-P5 were based on consultations with farmers, Africa RISING staff and local extension agents.

Our technology evaluation took place when farmers had already partially adopted and adapted different technology packages, providing valuable evidence for actual preferences or aversions towards them as well as their performance on farmer fields.

	Package #	Description*	Assumptions	Traditional practice
			Changes in labour and yields refer to traditional practices; Estimates for 'additional labour' were generated with local experts	
Baby Trials 15x $15m^2$	**P1** 	Fertilizer application on **maize**: improved seeds, row planting and double the 'traditional' amount of Sulphate of Ammonia (SA)	Fertilizer: 247 kg/ha NPK (15:15:15), 247 kg/ha SA (total: 90 kg of N/ha) Seeds: Improved seeds (cost: 3.3 GHS/kg), 21 kg/ha, row planting Average additional labour: 2.5h/ha; Assumed yield increase: 25%	Fertilizer: 247 kg/ha NPK, 123 kg/ha SA (total: 60 kg of N/ha) Seeds: recycled seeds, 5 kg/ha Seeds planted haphazardly along ploughing lines
	P2 	Improved **cowpea** variety (*e.g.* IT 99K 573-1-1), row planting and three sprays with Lambda cyhalothrin (2.5%)	Seeds: 20 kg/ha (cost: 6.7 GHS/kg), row planting sole cowpea Additional labour (harvesting): 2.5 h/ha Labour (per spray): 1.24 h/ha Assumed yield increase: 45%	Africa RISING uses 'one spray' as a control trial. Seeds: 10 kg/ha, improved variety
	P3 	Integrated Soil Fertility Management (ISFM) on **soybea**n including inoculum and Triple Super Phosphate (TSP)	TSP: 123 kg/ha (2.5 GHS/kg) Inoculum: 0.247 kg/ha (200 GHS/kg) Seeds: 37 kg/ha (cost: 4.6 GHS/ha), row planting; Total additional labour: 18 h/ha. Assumed yield increase: 50%.	No fertilizer Seeds: 37 kg/ha, broadcasted
Upscaled Trials 0.405 hectares (ha)	**P4** 	**Maize-legume rotation** with $2/3^{rd}$ of the area grown with maize and $1/3^{rd}$ with a legume (cowpea or soybean). If the farm area is large enough a 1:1 rotation was assumed.	Traditional fertilizer/spray on maize and legumes Additional labour: Maize (+2.5 h/ha) Cowpea (+5 h/ha), Soybean (+1.24 h/ha) Assumed yield increase for rotated maize: 50 % compared to maize after maize Cowpea: 2 sprays, 20kg/ha seeds. Soybean: no fertilizer	Continuous cultivation of maize
	P5 	**Maize-legume strip cropping**: 2 rows of maize, 2 rows of legume, with rotating strips from one year to another	Same as for the rotation, except labour: Maize (+3.7 h/ha) Cowpea (+7.4 h/ha), Soybean (+1.85 h/ha compared to the baseline).	Continuous cultivation of maize (possibly with intercropped legumes)

* all packages furthermore promote the use of crop residues as green manure or livestock feed instead of burning

Table 4.1. *Description and assumptions of Africa RISING technology packages (P1-P5). The traditional practices served as a reference to reset each case-study farm to a baseline i.e. to a state without any of the described Africa RISING technology packages.*

On single farms, crops were cultivated with 'traditional' and 'improved' practices, allowing a reconstruction of the original farm (the 'baseline': traditional and no Africa RISING practices) and an extrapolation of costs and benefits for scenarios in which all (relevant) fields would be managed according to project recommendations. Although the project is ongoing, implying a formative, real-time evaluation, we understand our work as an 'ex-ante assessment' since we compare an original state with a possible final state of implementation that has not (yet) been reached. We hence build baseline farms against which we compared scenarios for all technology packages and their whole-farm implications.

4.2.3. Typology approach

Operationalizing the farm systems diversity in our three case-study sites was fundamental for the selection of case-study farms. Existing typologies were too generic (Signorelli, 2016) or too specific (Kuivanen et al., 2016b). Signorelli (2016) used data from 50 different communities across the three northern regions while Kuivanen et al. (2016b) worked in three sites in the NR, excluding the UER and UWR. In both studies, resource endowment was the main differentiating factor, but while the statistical approach of Signorelli (2016) led to a grouping of farms (households), the participatory approach of Kuivanen et al. (2016b) resulted into a typology of farmers (individual household or community members).

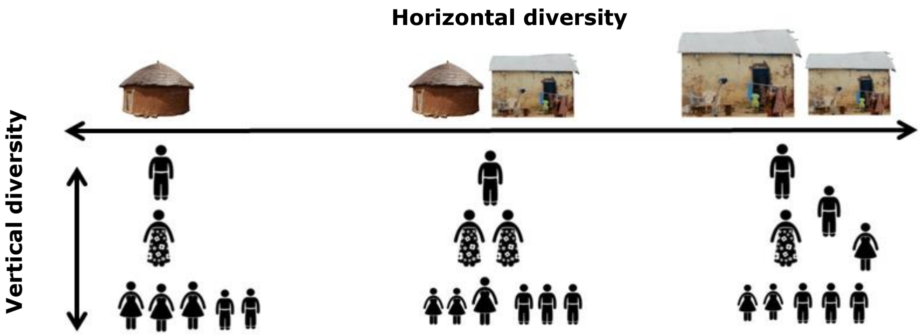


Figure 4.2. *Horizontal and vertical diversity of farm systems.*

To consolidate the general complementarity of a horizontal (among households) and vertical (among individuals) diversity (*cf.* Fig. 4.2) we held focus group discussions with men (n=7) and women (n=7) in Duko, Nyangua and Zanko.

Participants were consulted on local inter- and intra-household differences. The protocol for the focus group discussions is provided in Annex 4A. Both 'units of analysis', the household and its members, were unanimously described as important, with the household encompassing the totality of resources and shaping the decisions of related individuals, including decisions on technology adoption. Farmers used locally varying criteria to express different levels of resource endowment between households in their community. We therefore asked the focus group participants to describe features of low, medium and high resource endowed (LRE, MRE and HRE) farms in their locality (*cf.* Annex 4B) and to identify representative households for each farm type that we could visit for in-depth interviews. Subsequent household surveys served as entry points for investigating intra-household differences by separately consulting individual household members. Hence we used a simplified, community-validated and locally adjusted household typology to choose representative farm systems for further analysis.

By limiting farm types to the three categories of resource endowment (LRE, MRE and HRE) we aimed to (i) facilitate the debate in the focus group discussions by making contrasts more visible, (ii) ensure regional comparability of our results; and (iii) guarantee relevance to other household typologies based on resource endowment *e.g.* Signorelli (2016) and Kuivanen et al. (2016b).

4.2.4. Model-based analysis

Per farm type and per region we modelled one representative farm using the whole-farm model FarmDESIGN. FarmDESIGN is a bio-economic, static model complemented by a multi-objective optimization algorithm (Groot et al., 2012). The static model component allows a detailed analysis of the current farm performance and resource flows. The optimization tool is able to generate a large array of Pareto-optimal alternative farm configurations, constituting technical possibilities to re-arrange the farm, allowing the exploration of concrete options for sustainable intensification.

FarmDESIGN describes a farming system in terms of

- its physical components (fields, buildings, animals, crops, organic matter imports),
- associated inputs (capital expenditures, labour, fertilizers, pesticides, seeds) and
- associated outputs (income, grain yields, animal products).

Crop and livestock components are integrated and interrelated, mainly through feed supply and manure production. FarmDESIGN furthermore comprises information about each household member (gender, labour contributions, external or off-farm income or expenses), and captures environmental information on local climate and soils, as well as economic parameters such as the national interest rate, labour and land costs. The time horizon in FarmDESIGN simulations is a one-year period and hence the model requires cumulative annual figures such as yield or labour inputs per year. Model input data was obtained by conducting detailed household surveys and soil sampling in November 2015, complemented by expert interviews, literature and data (N=1284 households) of the Ghana Africa RISING Baseline Evaluation Survey (GARBES, 2014).

We used FarmDESIGN to perform three analytical steps for each selected farm system:

1. An analysis of the baseline situation and resource flows. Performance indicators: operating profit (GHS/yr), SOM balance (kg/ha) and labour requirements (h/yr) to represent economic, ecological and social elements of sustainability.

2. An evaluation of the five technology packages, tailored to the circumstances of each farm, for the selected indicators. Tailoring the packages involved two steps: (A) defining substitutions or appropriate additional areas for the project-proposed crops and (B) adjusting yield and labour assumptions if inputs at baseline were below the reference *i.e.* the 'traditional practice' (*cf.* Table 4.1).

3. An exploration (*i.e.* multi-objective optimization) of relations among different objectives (maximize profits, increase SOM balance and/or minimize labour balance) per case-study farm.

Each of the three steps was carried out in close consultation with household members of the nine case-study farms.

The survey tool, used to collect data on the actual farm configuration, is provided in Annex 4C. According to the local cultural norm, we conducted the survey with the (typically male) HHH. Subsequently, we also consulted the wife or wives and the oldest son or daughter. Together, the HHH, his wife and the oldest child were described as the social fundament of a local farm household ('*they are like the three stones under a cooking pot*') by the communities. The consultation of different household members served to triangulate information, leading to a more complete representation of the farm systems in FarmDESIGN.

Step 1, defining the baselines, required a modification of the actual farm configurations, removing all influences of Africa RISING. The baselines served as starting points for implementing the different technology packages (step 2), allowing to compare the farm performance under P1-P5 with the performance at baseline. Each technology package was implemented differently for each case-study farm (*cf.* Annex 4D), based on their existing farm configuration and constraints *e.g.* land or labour constraints, their cropping pattern and production orientation. Each farm configuration for each farm (the actual, the baseline and the farm under P1-P5) was built as a separate model in FarmDESIGN and can be downloaded as part of the supplementary materials (Annex 4E). The assumptions and changes underlying individual models are explained in the respective FarmDESIGN notes, accessible via the model user interface.

For step 3, the exploration, we allowed the model to extend the baseline by P1-maize, P2-cowpea and P3-soybean as well as a rotation (P4) or a strip cropping (P5), depending on which of the latter performed better in step 2. The model was given 'room to manoeuvre' *i.e.* it could choose to adopt the project-proposed practices or to maintain the current practice in order to fulfil the farm objectives within the given constraints *e.g.* feed requirements and spatial limitations. Decision variables were: the total farm area, the size of individual and household fields (with specific crops), feed imports and crop residue allocation. Household fields could increase according to communal land availability and household resource endowment. Individual field sizes, *i.e.* the fields of the son, daughter or the wife, were fixed (variation < 5%), since these have been negotiated with the HHH. Allowing the model to minimize or remove individual fields would override existing social structures, translating into socially inacceptable 'solutions' (alternative farm configurations). Increasing the field sizes of individuals would have been problematic, too, since the HHH is in need of the remaining land to feed and sustain the family. The differentiation of household and individual fields was particularly important for our case-study site in the NR, where it is common for women and adult children to cultivate individual fields. After setting decision variables, constraints and objectives, we ran an exploration at 1000 iterations, generating solution clouds of alternative farm configurations.

In August 2016 we re-visited all modelled farm households to jointly scrutinize the model assumptions (*cf.* also Annex 4D) as well as the results of the exploration. To ensure the technical accuracy of the model results, we asked members of our case-study households whether the model assumptions were sensible. We also asked if there was anything that, in reality, would make the particular technology package more suitable for them, therewith assessing the actual attainability of the model-proposed technical solutions. To test the validity of the exploration results (step 3), we asked which crop areas the farmer would increase or decrease when aiming for higher overall farm operating profits, a higher SOM balance or a lower labour balance. The farm objectives themselves were discussed, too, ensuring that these were indeed important for household members of our case-study farms. We furthermore described trade-offs, as suggested by FarmDESIGN, and asked whether or not farmers could relate to them. We also consulted farmers about the feasibility of selected 'alternative farm configurations' as generated during the exploration.

4.2.5. Weighted scoring exercise

To reveal intra-household differences in the evaluation of the five technology packages, we developed and used a weighted scoring technique, combining an assessment of the importance of evaluation criteria (0-3 range) with a scoring per criterion (-10 to +10 Likert scale) (Likert, 1932).

Based on previous adoption studies, we chose the following criteria for technology evaluation:

- **costs** (Bensch et al., 2015; Ellis-Jones et al., 2012; Ragasa and Chapoto, 2017; UNEP, 2013; Van Hulst and Posthumus, 2016; Waithaka et al., 2006),
- **labour inputs** (Becx et al., 2012; Britwum and Akorsu, 2016; Lalani et al., 2016; Meijer et al., 2015; Van Hulst and Posthumus, 2016),
- **accessibility** of inputs that need to be purchased (CSIR-SARI, 2012; Ellis-Jones et al., 2012; Waithaka et al., 2006),
- (cultural) **acceptability** (Abdollahzadeh et al., 2017; Coulibaly et al., 2010; Hunecke et al., 2017; Meijer et al., 2015),
- **ease of application** (Gao et al., 2017; Lalani et al., 2016; Van Hulst and Posthumus, 2016),

- impact of adoption on **product quality** (Abebe et al., 2013; CSIR-SARI, 2012),
- impact of adoption on **yields** (Aguilar-Gallegos et al., 2015; CSIR-SARI, 2012; Lalani et al., 2016; Murage et al., 2015) and
- impact of adoption on **soil fertility** (Ellis-Jones et al., 2012; Lalani et al., 2016).

Costs and accessibility refer to a situation where Africa RISING does not sponsor the inputs, matching with our assumptions in FarmDESIGN. We furthermore inserted open categories ('others, namely:') for additional criteria that would eventually be mentioned.

The first step of the scoring exercise was a determination of the importance of each criterion to each respondent, with '0 = not important, 1= low importance, 2 = medium importance, 3 = highly important'. We then asked each respondent how the individual technology packages performed in terms of each criterion, with answers ranging from '-10 = very poor performance' to '+10 = excellent performance'. Respondents were consulted separately, in absence of other household members. To evaluate the performance per package, respondents were asked to compare the packages to the traditional way of growing the respective crop *e.g.* to compare package P2 with traditional cowpea cultivation.

Multiplying the 'importance' (0-3) with the performance-scores (-10 to +10) resulted into a weighted evaluation per package in terms of each criterion. By adding up the weighted scores for the individual criteria we obtained an overall evaluation (score) for the technology package per household member. We used the average scores of all household members to compare evaluations at household level. The template of the scoring exercise is included in the farm survey of November 2015 (Annex 4C).

To test the significance of patterns in total scores per farm type and per region, we performed an analysis of variance (ANOVA) in R (version

3.4.0), including two- and three-way interactions between the regions, farm types, household members and technology packages.

4.2.6. Matching model results with farmer evaluations

As a final step, we compared the results of the model-based assessment with the evaluations by the different household members *i.e.* the farmers' perceptions of P1-P5. In FarmDESIGN, P1-P5 were evaluated according to the change in operating profits, the labour and SOM balance as compared to the baseline. We added up the percentage changes in terms of all three farm objectives in order to obtain a global model result per technology package. Since an increase in labour requirements impairs performance, labour increases were assigned a minus-sign.

The counterpieces to the model results were the following evaluation criteria of the weighted scoring exercise: the affordability and the impact on yields, changes in labour as well as the impact on soil fertility. Just like for the model results, we determined a global evaluation score by adding up the weighted scores for the mentioned subset of evaluation criteria per household member.

Since the units of analysis were different (percentage change versus weighted scores), we checked for a relative congruence *i.e.* whether packages that performed best in FarmDESIGN also received a similarly positive evaluation by the individual household members. We are aware that the chosen subset of evaluation criteria is not exhaustive. The subset, however, represents the core sustainability domains and allows a comparison of modelled and perceived performance.

4.3. Results

4.3.1. Farm features, constraints and opportunities

The nine case-study farms differed greatly in terms of cultivated area, crops, household size, livestock types and numbers. Figure 4.3 displays their key structural features. Differences were large among and within case-study communities. Across the three communities the same criteria served to evaluate household resource endowment. However, thresholds, especially for farm sizes, differed considerably between locations.

Figure 4.4 reveals that the operating profit per person (GHS/pp) is very similar among our case-study farms, despite large differences in profits per hectare. The indication of operating profits per person was based on the division of total farm profit by the number of household members, not on the actual distribution of financial resources within a household.

Households in Duko (NR) were relatively large and so was the resource gap between the LRE and the HRE farms in terms of land, livestock and crop diversity (Fig. 4.3). In Zanko (UWR), qualitative rather than quantitative differences defined the farm types: the LRE household in Zanko owned the largest land area (high quantity), but their fields were far away from the homestead and partly too stony to plough (low quality). The internal social cohesion was weak and the female HHH seemed marginalized and impoverished. Compared to the NR and UER, farms in Zanko (UWR) evinced more complex cropping patterns and a larger number of crops. Farms in Nyangua (UER) were smaller and evinced higher labour inputs (h/ha, particularly the MRE farm). However, they were more profitable (GHS/ha), with higher SOM balances than farms in the NR and UWR (*cf.* Fig. 4.4). All three LRE households owned little livestock, exemplifying the importance of crop-related soil fertility measures, with options limited to the use of green manures, apart from the random seasonal droppings of free-ranging animals. LRE households also owned little or no private means of transportation, hampering the transport of inputs and outputs from and to the local market as well as the transport of compost and manure to more distant fields.

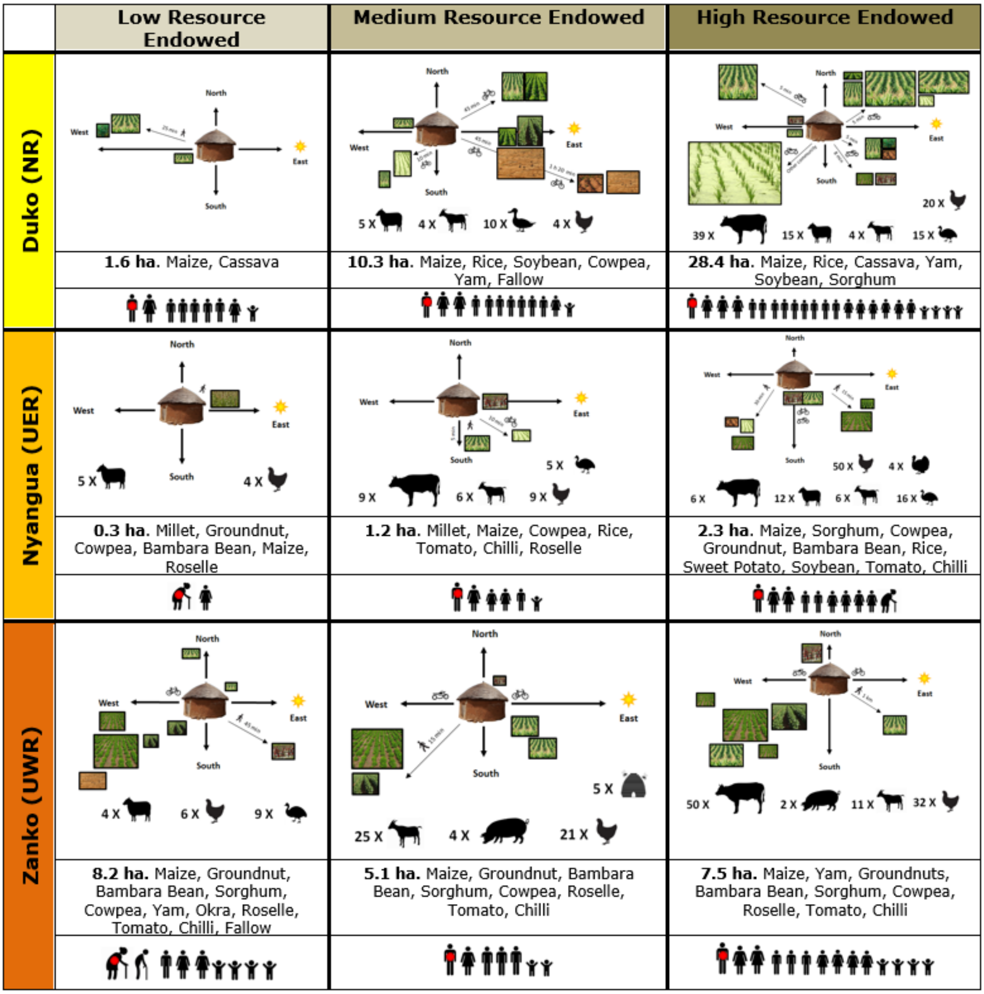
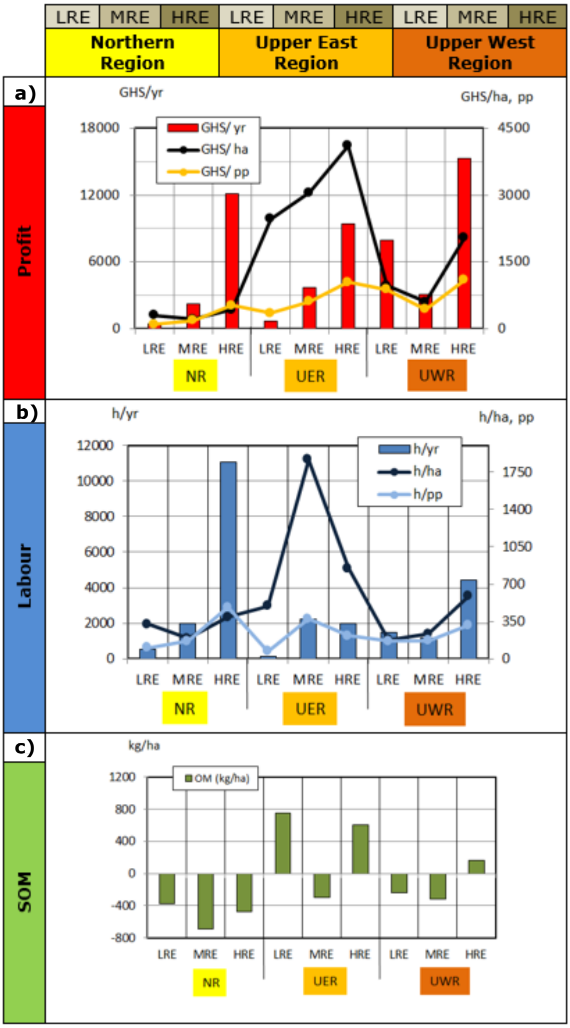


__Figure 4.3.__ Overview of actual, structural farm features at baseline. The maps provide a graphical overview including crops, livestock and distances to fields. Total farm size and cultivated crops are listed. The human icons represent the household composition with red dots marking the female or male household head.

LRE farms also evinced relatively low labour inputs and a low ownership of and access to agricultural machinery and tools, confirming the strong labour constraint as reported during focus group discussions and household interviews.



pp = per person; 1 Ghanaian Cedi (GHS) = 0.23 USD (18.5.2017)

Figure 4.4. *Model-determined baseline performance per farm in terms of operating profits (a), labour inputs (b) and the soil organic matter (SOM) balance (c). The coloured bars are associated to the primary axes and display the total annual profits (in GHS), labour (hours) and SOM (kg/ha) per farm. The black and the coloured lines are associated to the secondary axes, indicating profits and labour inputs per hectare (ha) and per person (pp) respectively.*

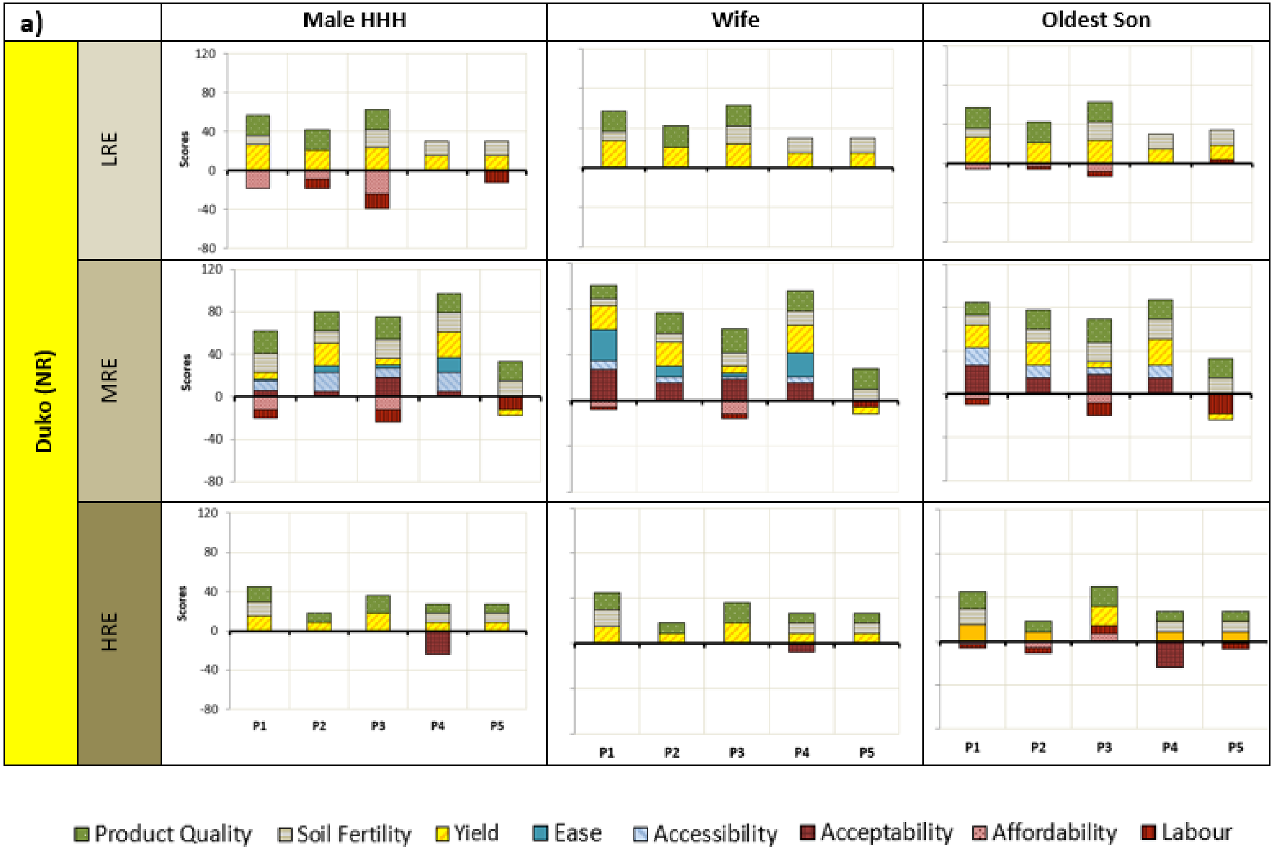
4.3.2. Technology evaluation by different household members

Figure 4.5 reveals the detailed results of the technology evaluation, showing each members' awarded scores per evaluation criterion per technology package. Households and household members differed significantly in their evaluation of the five technology packages, with a pattern of LRE households tending to be least positive among farm types (***P <0.001) and women more positive than the male members of the same household (**P = 0.0937).

Concerning differences between farm types, LRE households in the UER and UWR gave the lowest total scores to the packages (Fig. 4.6 b and c), mainly based on perceived high labour inputs and costs (Fig. 4.5). Labour and affordability are major constraints for the LRE households in Duko (NR), too, but HRE household members of the same community gave even lower scores to the packages. The HRE household showed a generally low enthusiasm and low expectations towards the benefits of the technology packages. Among all interviewees, only members of this (HRE) household assigned negative scores to the 'acceptability' of technology packages (P4 or P5). This finding can be contextualized by a statement of the HHH, who indicated to be resentful of low and medium resource endowed households, since for his household the project support made less of a difference than for LRE and MRE households, distorting competition. Concurrently, members of LRE and MRE household of the same community uttered hopes to 'catch up' with HRE households in their community with members of the MRE household, in fact, assigning positive scores to the acceptability of the technology packages (P1-P4). In Nyangua (UER), the strongly negative scores of the LRE household stand in stark contrast with the low or no negative scores given by the MRE and the HRE household of the same community (*cf.* Fig. 4.5). The sensitivity towards costs and labour can, however, be explained by the poor baseline performance of the LRE household. For Zanko (UWR), we observe a large gap in the evaluation of P3 between the LRE household (negative) and the MRE and HRE household (positive). We observed that HRE households in all three sites give no or low negative scores to the technology packages (negative scores were significantly smaller than for LRE and MRE; ***P < 0.001), indicating a general feasibility, including the critical factors: costs and labour.

Concerning differences within households, Figure 4.6 (d, e, f) shows that women were mostly more positive about the technology packages than men of the same household. Exceptions to this pattern are the MRE household (P2-P3) and HRE household (P3) in the NR as well as the MRE household in the UWR (P2-P5), with the latter evincing the most pronounced differences. Male household heads were more concerned than other household members about affordability and labour demands, which was particularly significant within LRE households with ***P <0.001 for affordability and **P < 0.01 for labour concerns. Furthermore, women seemed to be consistently more positive than men about P1, although this difference was not significant (P=0.7646). No patterns were observed in scores given by the oldest sons or daughters-in-law, sometimes being more, sometimes less positive than other household members (Fig. 4.5).

During the focus group discussions, many farmers reported to only adopt single components of the packages. Adopted components can be categorized as management (technique) changes rather than technology changes. For instance, farmers adopted row planting, applied more precise amounts of fertilizers per plant, paid more attention to the timing of the application, became more precise in crop spacing and indicated greater efforts in using green manures. The purchase of technologies, such as seeds and agrochemicals, was hampered by high (perceived) costs and, in Zanko, by low levels of trust towards input dealers due to quality concerns.


a)
Male HHH
Wife
Oldest Son
Duko (NR)
LRE
MRE
HRE
Scores
120
80
40
0
-40
-80
P1
P2
P3
P4
P5
Product Quality
Soil Fertility
Yield
Ease
Accessibility
Acceptability
Affordability
Labour

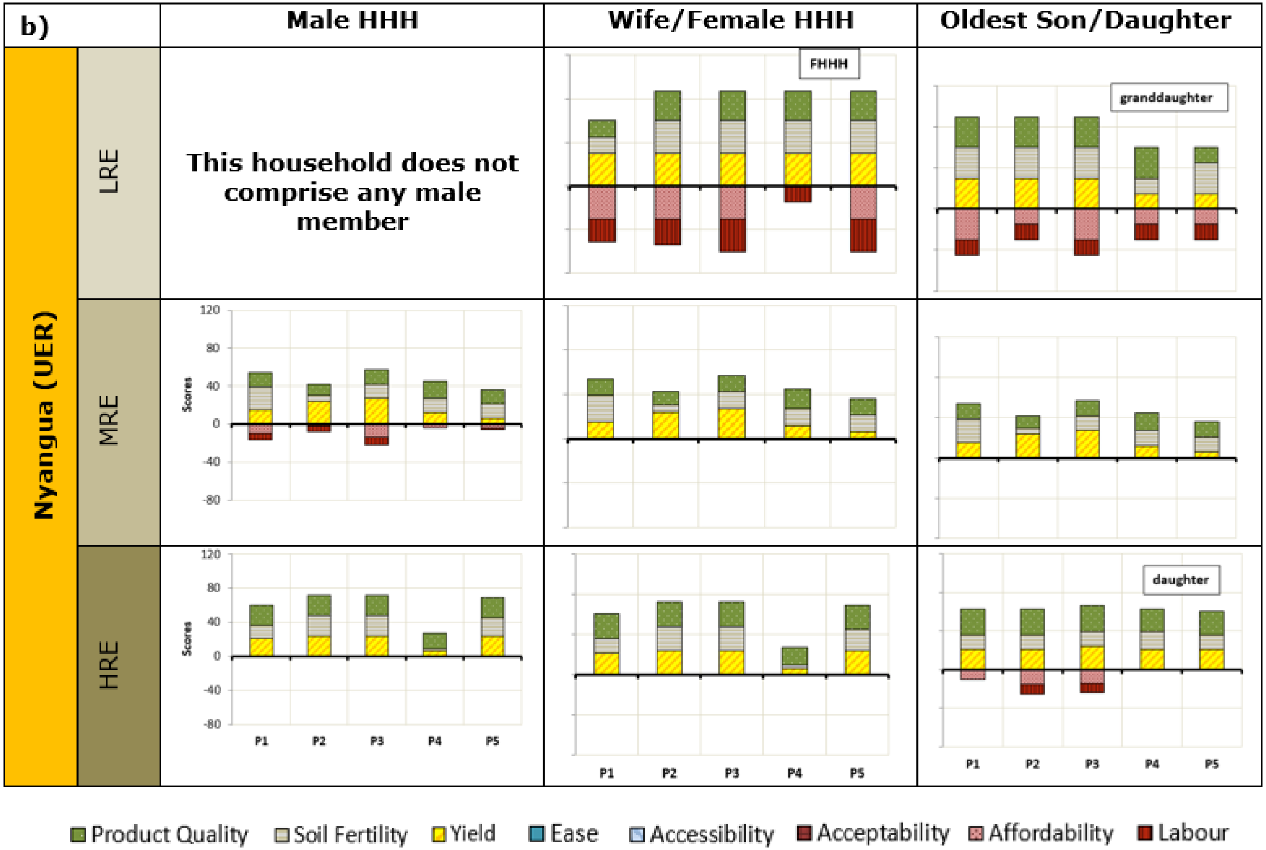

b)
Male HHH
Wife/Female HHH
Oldest Son/Daughter
Nyangua (UER)
LRE
MRE
HRE
This household does not comprise any male member
FHHH
granddaughter
daughter
Scores
120
80
40
0
-40
-80
P1
P2
P3
P4
P5
Product Quality
Soil Fertility
Yield
Ease
Accessibility
Acceptability
Affordability
Labour

Figure 4.5. *Technology evaluation in a) Duko (Northern Region) b) Nyangua (Upper East Region) and c) Zanko (Upper West Region). The Y axis indicates the cumulative scores given to the five technology packages by the different household members. Each criterion (expressing performance in terms of yield, labour etc.) is represented by a different colour in the stacked columns. P1-P5 are aligned on the X-axis.*

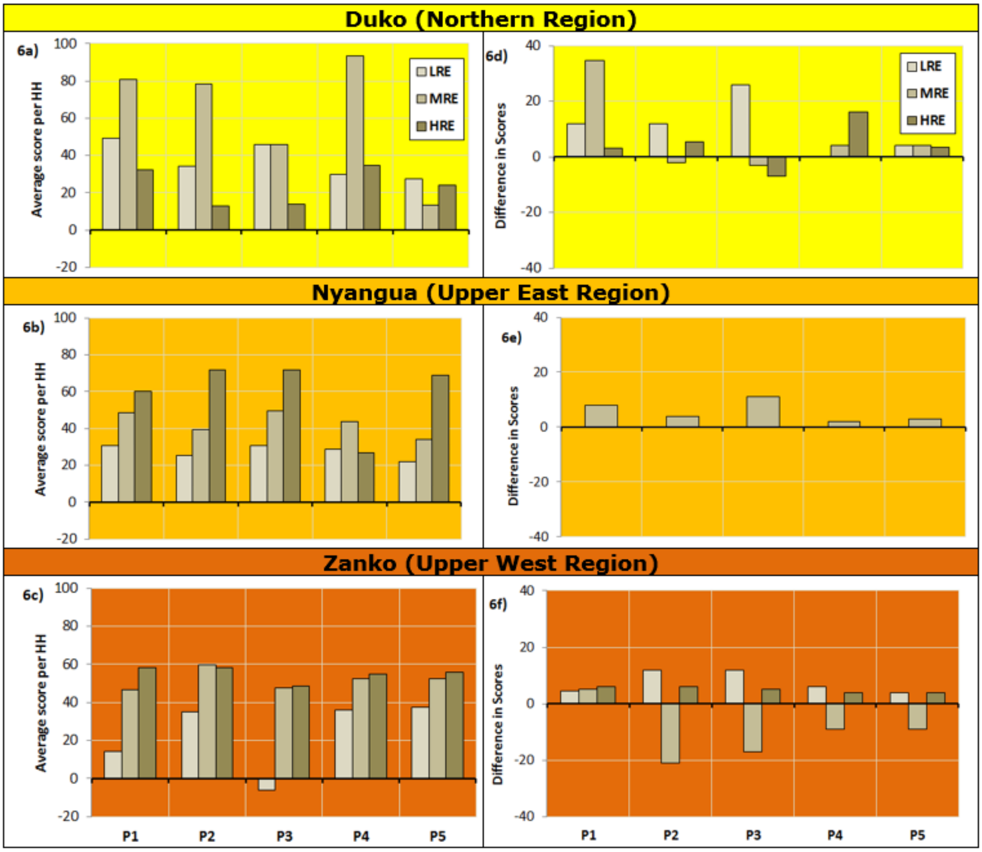


Figure 4.6.*Fig. a, b, c: Average scores per package, per type and per region. Fig. d, e, f: Difference in scores between men and women of the same household. For Fig. a, b and c, averages were taken from the aggregated evaluation scores of all members per household. For Fig. d, e and f, the scores refer to the average total evaluation score per package for men and women respectively. A positive value indicates a more positive overall evaluation by women as compared to men of the same household. The LRE and HRE households in the Upper East have been omitted, since the former has only female household members and for the latter the evaluation of men and women was the same.*

4.3.3. Impact assessment of technologies in FarmDESIGN

Figure 4.7 shows the model-determined impacts of P1-P5 on operating profits (GHS/yr), the labour balance (h/yr) and the SOM balance (kg/ha/yr) for each case-study farm. In about 40% of all scenarios, the profits increase together with labour inputs, suggesting a trade-off between the two farm objectives.

Comparing the impact of P1-P5 per farm type, LRE farms experienced the greatest relative but lowest absolute benefit in terms of profits. LRE farms are most heterogonous concerning the impact of P1-P5 on their SOM balance and the operating profit, with the LRE farm in Duko (NR) experiencing the largest improvements (increasing profits and SOM balance) and the LRE farm in Nyangua (UER) performing worst (increase in labour and decrease in SOM balance) among the nine farms. The disproportionate increase in labour for the LRE farm in Nyangua is associated to the extremely low baseline labour inputs of the farm as well as the relatively large area on which the packages were implemented, rendering the total farm performance sensitive to even small increases in labour requirements.

Concerning regional patterns, the LRE and the HRE farms in Duko could improve their farm performance most among all case-study farms. All three farms in Duko achieved best results under P2 while the LRE and HRE farm also benefitted substantially from P4 and P5. Package 3 did not do well in Duko, while it performed well in Zanko (UWR): operating profits and the SOM balance increased for all three farms in Zanko, while labour decreased (LRE) or increased at a lower rate than profits (MRE and HRE). In Nyangua, the packages had highly divergent impacts on the different farm types: the LRE farm experienced a substantial relative increase in profits for P2-P5, a sharp increase in labour and a drop in the SOM balance. In contrast, the MRE and HRE farms experienced only slight increases *e.g.* the MRE farm improved in terms profits and SOM under P1 and the HRE farm increased labour under P3. The dissimilar magnitude of impacts among case-study farms in Nyangua was largely determined by the share of the total farm area set under P1-P5, indicated by the black dots connected by a dotted line in Figure 4.7.

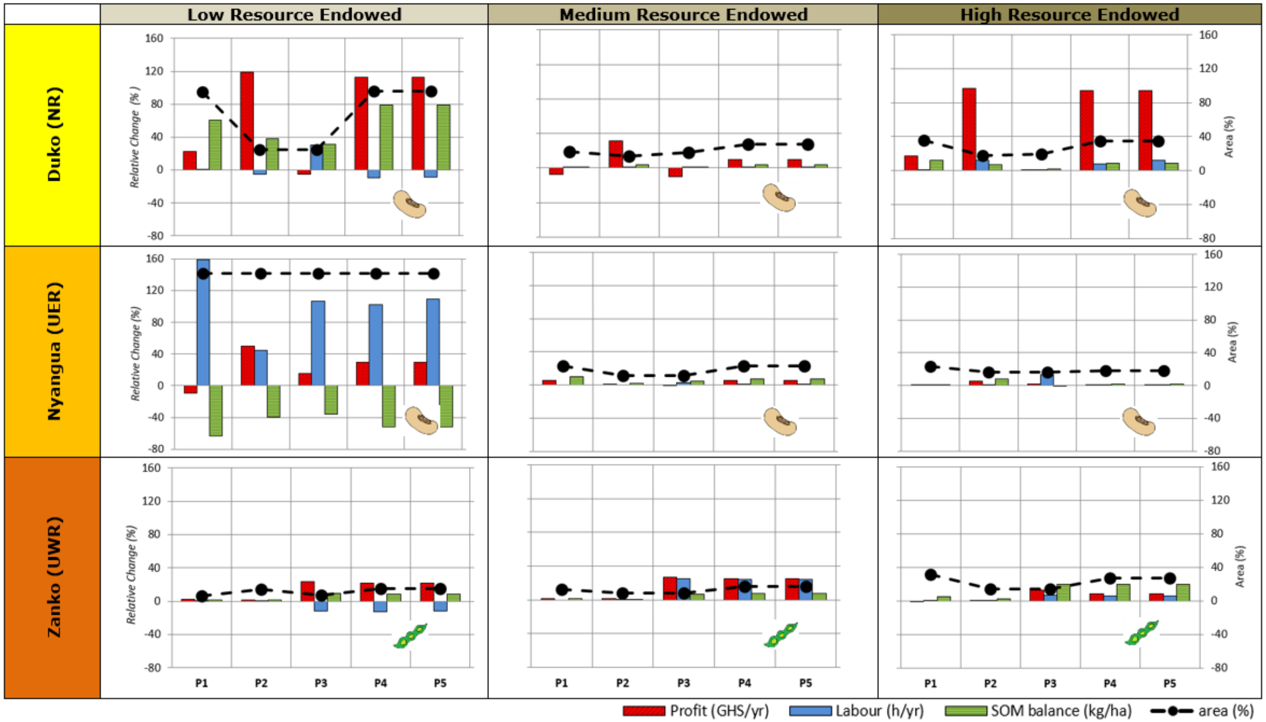


Figure 4.7. *Model-based impact assessment of P1-P5. The X axis lists the technology packages (P1-P5). The Y-axis expresses the relative change for P1-P5 as compared to the baseline in terms of profits (GHS/yr), the labour balance (h/yr) and the SOM balance (kg/ha). The baseline is a farm's actual configuration without any Africa RISING practices. For the impact assessment, P1-P5 have been separately implemented on and compared to the baselines. The cowpea or soybean symbols indicate the legume choice for the rotation and the strip crop (P4 and P5) per farm.*

In general, we can establish that the greater the areal share of a package, the more pronounced its impact on the whole-farm performance. Package 2 and its impact on the three farms in Duko seems to constitute an exception, due to the high local profitability of cowpea. In Zanko, all three case-study farms would respond most to P3-P5, with the commonality that soybean was cultivated on all three farms in P3-P5.

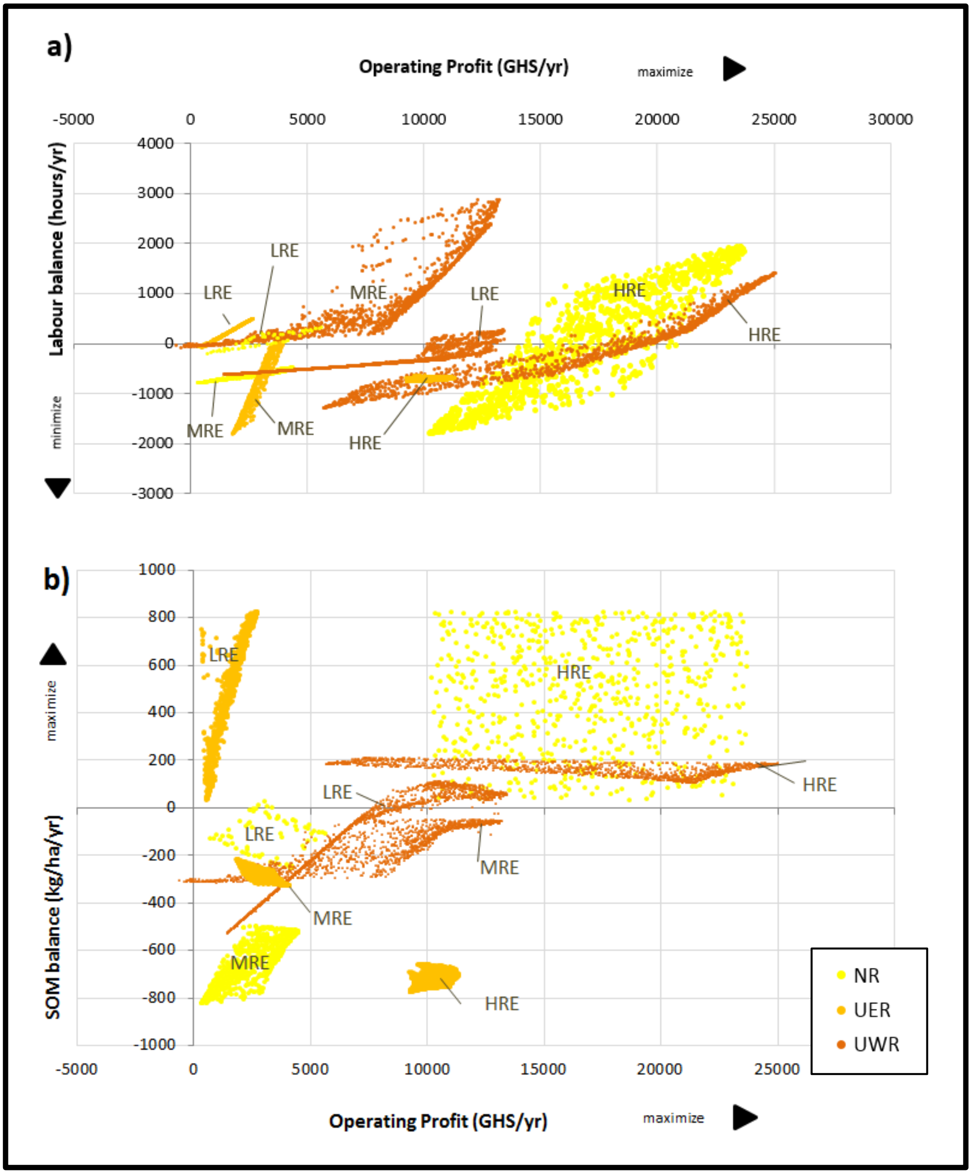
4.3.4. Exploration of alternative farm configurations

Figure 4.8 presents results of the multi-objective optimization in FarmDESIGN. The scatter plot demonstrates a trade-off between improving farm profitability and reducing labour demand (Fig. 4.8a) as well as a synergy between profitability and increasing SOM balance (Fig. 4.8b). At baseline, the labour balance is zero, expressing that current labour requirements are met.

Higher resource endowment generally resulted in a larger room to manoeuvre; *i.e.* with increasing resources a household has more options to favourably rearrange its farm configuration. The link between endowment and size of solution space holds true when comparing farms per type and per region.

Farms in Zanko (UWR) had the largest room to manoeuvre in terms of operating profits. For these farms Pareto-optimal solutions were found in a wide range of profitability from 0 to 13000 GHS/yr for LRE and MRE farms, and between 6000 and 25000 GHS/yr for the HRE farm. At higher profitability, the labour demand strongly increased due to increased incorporation of P3-soybean, which is profitable but increases labour requirements. For most farms an increase of SOM balance was possible at farm configurations in the lower range of profitability, but at higher profitability levels the attainable SOM stabilized.

Compared to the NR and UWR, for farms in Nyangua (UER) there were limited options to improve in the three selected performance indicators, with the largest room to manoeuvre for the LRE farm, particularly in terms of the SOM balance.



1 GHS = 0.23 USD (18.5.2017)

Figure 4.8. *Model-generated solution clouds. Each dot represents an alternative farm configuration in terms of operating profits and labour (a) and the SOM balance (b). The regional solution clouds are differentiated by colour, see legend. In both scatter plots, operating profit is plotted along the X-axis. The arrows indicate the desired direction of change in terms of the three farm objectives.*

During the feedback sessions, farmers confirmed that the modelled scenarios were correctly determined *i.e.* farmers could relate to the alternative farm configurations. However, farmers also reported the more profitable options to require an initial investment, which was too high, particularly for LRE and MRE farms. Lack of credit was one of the main concerns raised during the focus group discussions and during the household interviews.

4.3.5. Model results versus farmer realities

Figure 4.9 juxtaposes the results of the impact assessment in FarmDESIGN with the technology evaluation by the different household members. Farmer evaluations were often more positive than model results would suggest. For MRE and HRE farms in both Nyangua (UER) and Zanko (UWR) the model predicted limited benefits of all packages, while the household members provided quite positive evaluations. For MRE and HRE farms in Duko (NR), the expectations of household members concerning P2, P3 and P4 did not align with model assessments. For LRE farms there was agreement between farmer evaluations and the model results, except for P1 in Nyangua for which the model predicted a negative impact, and for P3, which was expected to perform poorly by either the model (in Doku, NR) or by the farmers (in Zanko, UWR).

Within households, model results seem more aligned with the perception of male than female members[3]. During the evaluation, male household members placed greater emphasis on profits and labour requirements than women of the same household (Fig. 4.5).

[3] For the LRE farm in Duko (NR), the MRE farm in Nyangua (UER) as well as the LRE farm and HRE farm in Zanko (UWR) the pattern of the evaluation of the male HHH or the oldest son was most similar to the model results. For the MRE and HRE farm in Duko and the HRE farm in Nyangua the evaluation by the HHH and the wife were very similar or the same. The LRE household in Nyangua has no male household member.

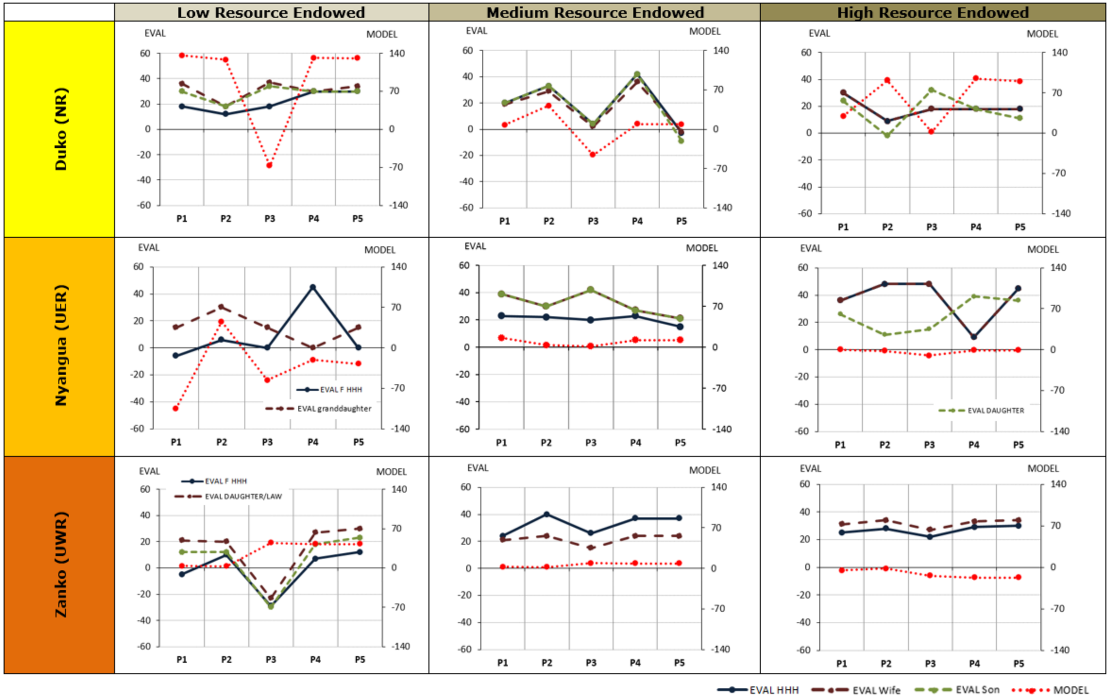


Figure 4.9. *Model results versus farmer evaluations. The red dots display the model results (sum of %-change in profits, labour and SOM), which are assigned to the secondary axis of the graph. The blue, brown and green dots are associated to the primary axis and show the respective counterpieces from the evaluation (sum of scores for affordability, labour, yield and soil fertility) per household member. The household members typically are the male HHH, a wife and the son, unless stated otherwise in the individual charts.*

Men heavily penalized a poor performance in terms of affordability and labour demands. For instance, in the LRE and HRE households in Duko (NR), the poor model-determined performance of P3 matched with the low scores given by the male HHHs and sons, while the wives were significantly more positive about the package. An exception to this pattern is the MRE household in Zanko (UWR), where model results were more closely related to the positive perception of the wife, projecting an increase in profits and the SOM balance.

For the LRE and the HRE household in Duko, the trend was inverted: most model projections were highly promising while the scores given by the household members to these packages were relatively low. The gap between 'technical potential' and 'social perception' was one of the greatest for the LRE farm in Duko, mainly due to apprehension about costs and labour inputs.

4.4. Discussion

Large differences prevailed among and within farms of different types and regions in terms of their current farm performance, the interest in and impact of the different technology packages (*cf.* Table 4.1) as well as their room to manoeuvre: LRE farms were projected to benefit most in relative and least in absolute terms. LRE households also gave the lowest scores to the packages. Only members of the HRE household in Duko (NR) gave lower scores: while model results were highly promising, the technology evaluation was shaped by a deeper social repulsion as expressed by the HHH. For the HRE household, financial feasibility or labour requirements were no constraints. Costs and labour constraints were, however, a central concern for members of LRE and MRE households, manifested during the focus group discussions, the technology evaluation and the feedback sessions on the results of the exploration: farm configurations of higher profitability typically required initial investment costs, constituting an obstacle especially for LRE and MRE households. Investment costs concern the purchase of seeds and agrochemicals. Our findings are in line with Ragasa et al. (2013), Akudugu et al. (2012) and

Martey et al. (2014) who associated low fertilizer application rates with financial constraints and a poor access to credits. Improving farmers' access to (input) credits and saving schemes is hence likely to improve technology adoption by low and medium resource endowed farmers. For future modelling work, the aspect of affordability should be given greater attention. An upper limit for 'initial investment costs' could be introduced, leading to rejection or 'penalties' associated to 'expensive' farm configurations during the exploration. Within farms, concerns about costs and labour were more prominent in the evaluation by male than female household members, in particular for LRE households. Since maximizing profits and minimizing labour were two of the three objectives used in FarmDESIGN, we observed a closer match between model results and the male perspectives. Since the chosen subset of evaluation criteria seems to have led to a gender bias in our model results, we recommend future model-based studies to perform an early stage assessment that determines the importance of different evaluation criteria to different household members. Including criteria that are of high importance to single gender categories (like young men or elderly women *etc*.) ensures a greater social fit of model results with farmer realities. Despite the greater fit between model results and the male evaluation, women were generally more positive about the technology packages than men. This finding is in line with observations of Britwum and Akorsu (2016) and Emmanuel et al. (2016b) who reported women having limited access to agricultural information, rendering women more eager than men to learn about and try out new technology packages.

Most interviewees gave high positive scores to the technology packages during the evaluation, while the model results did not suggest the same magnitude of potential positive change. The positive perceptions may point to hidden opportunities or to an overestimation by farmers due to insufficient own experience and information as well as a desirability bias (Spector, 2004). The mismatch may be resolved by fostering a more regular exchange of knowledge, assumptions and experiences between farmers and researchers. Furthermore, the different package components seem to be differently affordable and accessible for different households and household members, depending on their resource endowment: within households, according to Kuivanen et al. (2016b), the male household head may be described as an HRE individual, owning the land, strongly shaping household decisions and having easier access to agricultural inputs, while the wife or wives are described as LRE. Britwum and Akorsu (2016), Mustapha (2016) and Martey et al. (2014) also report women to have less access and fewer financial means to purchase inputs (technologies). Technologies and techniques are hence differently accessible to farms and farmers of different resource endowments. While techniques (methods) imply behavioural changes, technologies have to be purchased, making the former more and the latter less attractive for LRE and MRE farms and farmers. HRE farms or farmers, in contrast, can afford purchasing new technologies, being less pressured to adopt behavioural changes. The better a project knows their target group in terms of its socio-economic and institutional constraints and incentives, the better technology packages can be tailored and communicated to meet the farmers' actual needs.

The scoring exercise showed that households are usually not a coherent decision-making unit. In line with socio-psychological research (Brauer and Bourhis, 2006; Pollard and Mitchell, 1972; Von Schlippe and Vienna, 2013) we suggest that adoption 'decisions at household level' are the result of a complex interplay between the interests and power positions of the different household members. This paper explored differences in interests but did not address power distribution within households. Furthermore, trade-offs in resource allocation were measured in terms of profits, labour and the SOM balance, but the different farm configurations may be more or less suitable for different household members *i.e.* on-farm changes may imply social trade-offs. Identifying farm configurations that are associated to a low or negative degree of satisfaction for one or more household members would enable to exclude model results that are socially unrealistic. Investigating power distribution as well as social trade-offs within our case-study households would constitute a logical next step for this research.

With this research, we revealed patterns, explained mismatches and contextualized extremes with personal narratives. The inter- and intra-household perspective constitute two viewpoints that importantly complement each other. Projects like Africa RISING may use our findings as a basis for a larger-scale testing of patterns identified among our case-study farms and farmers.

4.5. Conclusions

Research for Development projects such as Africa RISING promote technology packages to address local agricultural challenges including low yields, low soil fertility as well as the low quality and quantity of inputs. In this paper we operationalized local farm systems diversity by using typologies and performing a systematic review of intra-household differences concerning the evaluation of the five technology packages. Through this research we achieved a better understanding of how different technology packages are perceived and are expected to impact different farm types. Among farm types, model results suggest the largest relative increase in farm profitability for LRE farms, particularly upon adoption of P2-cowpea, a P4-rotation or a P5-strip crop. During the technology evaluation, LRE and MRE farmers indicated, however, investment costs and labour to limit technology adoption. While P2-cowpea performed well among farms in Duko (NR) and Nyangua (UER), P3-soybean performed better among farms in Zanko (UWR). The comparison of model results and farmer evaluations showed that farmers were more positive about the technology packages than the model results would suggest. An alignment of model- with farmer evaluations may be achieved through a more regular and in-depth exchange of knowledge, assumptions and experiences between farmers and researchers.

Within households, women were generally more positive about the technology packages than men. Men attributed a greater importance to profit increases and a stable labour balance than women of the same household, translating into a greater correspondence of model results with the male perspective. We conclude, that evaluation criteria must be carefully selected to avoid a gender bias. The combined application of community-validated farm typologies, whole-farm modelling and farmer evaluations allowed a nuanced impact assessment of technology packages, advancing to bridge the gap between model results and farmer realities. We conclude that operationalizing inter- and intra-household diversity is a fundamental step in identifying sensible solutions for the challenges smallholder farm systems face in Northern Ghana.

Chapter 5

5. How do farm-level decisions come about?

Based on:

Michalscheck. M., Groot, J.C.J. and Tittonell, P.A. (2018). Beneath the surface: intra-household dynamics and trade-offs in resource allocation decisions of smallholder farmers.

Submitted.

Abstract

Globally, 83% of all farm systems are smallholder farms, challenged to become more productive, yet more resilient and sustainable in order to cope with an increasing resource pressure, growing food demands as well as climate change. Research for Development projects have generated large numbers of technical options for alternative farm designs, implying different resource allocation options. But what do these options mean to whom within a household? And how do decisions come about? We dive beneath the social surface of farm households in Northern Ghana to examine land allocation options for their power backing and associated intra-household trade-offs, applying concepts of economics, socio-psychology and physics. We reveal conflicting interests and a mismatch between 'ascribed power' and 'exerted power' suggesting that social power may be overruled or withheld. Power may be withheld if investments and risks, associated with a negotiation, outweigh the expected utility. Individual and household-level utilities furthermore exposed the social unacceptability of many technically promising land allocation options. Technical options hence must be evaluated ex-ante for their likelihood of acceptance and social implications to ensure their basic viability and sustainability.

Keywords: decision-making; FarmDESIGN; power dynamics; smallholder; social trade-offs

5.1. Introduction

Globally, farm lands are diminishing and degrading due to urban land expansion and unsustainable soil cultivation practices (Abass et al., 2018; Bren d'Amour et al., 2017; Lambin and Meyfroidt, 2011; Montanarella et al., 2016). Concurrently, food demands are increasing and climate change (IPCC, 2014) reinforces uncertainties in agricultural production, calling for more resilient yet more productive and sustainable farm systems (DeFries and Rosenzweig, 2010; FAO, 2011; Tilman et al., 2011). To assist farmers and policy makers in envisioning and evaluating alternative farm designs, Research for Development (R4D) projects have proposed a wide range of alternative land allocation options (Kaim et al., 2018; Law et al., 2015; Le Gal et al., 2011; Michalscheck et al., 2018a), implying changes in crop production, agricultural inputs and labour requirements. Worldwide, 83% of all farm systems are smallholder family farms, where household members engage into agricultural activities in a well attuned labour division (Doss, 2018; Graeub et al., 2016; Herrero et al., 2017) emerging from cultural norms and individual negotiations (Fafchamps, 2011; Pretty and Ward, 2001). Gendered production patterns are particularly pronounced among the typically multi-agent smallholder farm systems in South America, Africa and Asia (Akter et al., 2017; Alwang et al., 2017; Delêtre et al., 2011; Doss and Morris, 2001; Kevane, 2012), but little is known about what different resource allocation options mean for whom within a household, nor how decisions actually come about.

While multi-agent decisions are described to result from the interplay of interests and power positions (Haddad et al., 1997; Kusago and Barham, 2001; Michalscheck et al., 2018a; Purnomo et al., 2005; Schwilch et al., 2012), interests and power are rarely addressed jointly in research on household decision-making (Kusago and Barham, 2001). Interests are typically discerned through an indirect, inferential approach (Doss, 2013; Thomas, 1990). Only few studies use more complex, yet more accurate (Doss, 2013) direct methods such as contingent valuation and gaming approaches (Kusago and Barham, 2001; Michalscheck et al., 2018a; Ngigi et al., 2017; Prabhu, 2010). Power is typically assessed through proxies such as the relative asset control of spouses (Ali et al., 2016; Allendorf, 2007; Browning et al., 2013; Kusago and Barham, 2001). Few studies capture power directly consulting the husband and wife about respective percentage shares (Anderson et al., 2017) or categorical dominance in decision-making (Alwang et al., 2017; Becker et al., 2006; Ghuman et al., 2006; IFPRI, 2012; Story and Burgard, 2012). The husband and one wife are typically the only household members considered in studies on intra-household differences (Anderson et al., 2017; Kazianga and Wahhaj, 2017; Kusago and Barham, 2001), while many smallholder households are large and sometimes polygamous with likely more than two actors affecting and being affected by decision-making (Doss, 2013; Paresys et al., 2018; Tittonell, 2014). We address the need for a more inclusive, concise and simple approach for the joint assessment of intra-household interests and power positions and for relating the resultant insights to proposed alternative farm designs.

This study is part of the R4D project Africa RISING (Research in Sustainable Intensification for the Next Generation: https://africa-rising.net/) which, so far (2012-2017), trained about 52 000 smallholder farmers in Mali, Ghana, Tanzania, Malawi, Zambia and Ethiopia in technologies and techniques for sustainable intensification. Until 2021, Africa RISING aims to reach more than 1 million smallholders. Changes in farm management derive from decision-making processes and hence we demonstrate our methods and results for decision-making processes within smallholder farm households in Duko, one of 25 Africa RISING intervention communities in Northern Ghana (Larbi and Hoeschle-Zeledon, 2015). Like most communities in Northern Ghana, Duko is characterized by labour intensive mixed crop-livestock systems (Michalscheck et al., 2018a), patrilineal land tenure and high (urban) land pressure (*cf.* Annex 5A). We focus on land allocation decisions and on three locally important crops, namely maize (mainly food crop), cowpea (food and cash crop) and soybean (mainly cash crop). We assess interests and power positions (*cf.* Annex 5B) through a direct scoring approach as part of a household survey (*cf.* Annex 5C). Classic decision theory holds that a person's decision, when confronted with various choices, depends on his or her subjective expected utility *i.e.* on the likelihood as well as the benefits associated with a particular choice (Kubanek, 2017; Pollard and Mitchell, 1972). We express benefits as utility, multiplying utility with the power share (*Pi*) to determine the relative likelihood of the possible, crop-specific land allocation choices, visualized by power-weighted utility (PWU) curves. Since utility may be differently defined by different actors we capture each respondents' self-reported level of satisfaction (Berg and de Jong, 2002). Yet, the individual statements on preferences for land allocation options are comparable since they are each anchored in the respondent's ideal area (100%-satisfaction), followed by a standardized and step-wise enquiry about loss of satisfaction towards the minimum and the maximum acceptable (0%-satisfaction) crop area (*cf.* Annex 5C).

We compare three models to describe and predict decision-outcomes resulting from the interactions of interests and power positions at household level: (1.) the generic decision rule, assuming that by default only the male household head (HHH) holds power and enforces his interests. (2.) The utility-power model, predicting the decision-outcome to be that option with the greatest household-level approval and power backing (PWU), neglecting conflicting interests and power shares. (3.) A model based on Newtonian principles in physics, expressing interests (direction) and social power (magnitude) through vectors as in a parallelogram of forces, determining the mathematically consequent compromise (resulting vector) between all preferences (ideal areas) of the different household members (*cf.* Annex 5D). The predictive accuracy of each model is assessed through comparing the model predicted crop areas with the actual crop areas. Finally, we exemplify the applicability of utility levels to alternative farm configurations (*cf.* Annex 5E), building on existing (Michalscheck et al., 2018a) whole-farm model results for Northern Ghana.

5.2. Results

5.2.1. Gender, power and resource endowment

According to respondent's triangulated self-reports, male HHHs held the bulk of the power, explicable by their 'provider'-role and hereditary connection to the farm land (Bourguignon et al., 2009; Britwum and Akorsu, 2016). The power share of the sons was positively correlated with livestock ownership (r_s=0.556; p<0.05), total farm land (r_s=0.651; p<.01) and household size (r_s=0.507; p<0.01), *cf.* Figure A5.6 (Annex 5). The power share of the wives was negatively correlated with the sons' power share (r_s=-0.557; p<.05), indicating her influence to depend on the presence of an adult son.

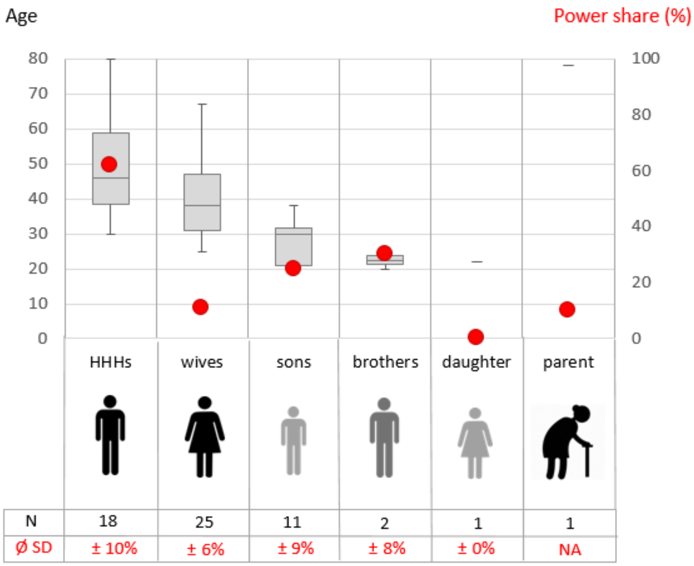


Figure 5.1. *Age and power share (%) per household member category. The grey boxplots display the age distribution and the red dots the average, triangulated power share per member-category. The (N) numbers indicate the count per member category. The 'ØSD' indicates the average standard deviation in self-reported, non-triangulated power shares per member in each category.*

Among men, the power share was found to be positively correlated (r_s=0.587; p<0.01) with age, while no significant correlation was found between the age of women and their power share. Figure 5.1 illustrates the age distribution and the average self-reported power share (%) per household member category.

We found disagreements on ideal crop areas among household members in 74% of the cases. In line with their particular roles and production objectives, wives and sons were interested in larger cowpea and soybean areas and in smaller maize areas than the HHHs (*cf.* Annex 5F). The ideal area of cowpea was furthermore positively correlated with the power share (r_s=0.658; p<0.01) and age (r_s=0.491; p<0.05) of a respondent.

5.2.2. Utility curves and utility-power model

We generated 174 individual utility curves, one per person (N=58) and per crop (N=3), and 54 aggregated utility curves, one per household (N=18) and per crop (*cf.* Annex 5G). At the actual area, the average satisfaction differed between household members ($\eta^{2=}$0.158) with 96% of average satisfaction among HHHs, 75% among sons and 55% among wives, indicating social trade-offs in existing decision-outcomes. In cases of intra-household disagreements, land-allocation decisions corresponded to the preference of one household member, mostly the powerful HHH (90%), instead of being a compromise between the prevailing different interests. When adding the power dimension to the utility curves, in 90% of cases with disagreements, the PWU-curve peak was congruent with the actual area *i.e.* the utility-power model enabled a highly accurate prediction of the actual decision-outcome. Figure 5.2 illustrates the utility curves of one household excluding (left) and including (right) the power shares.

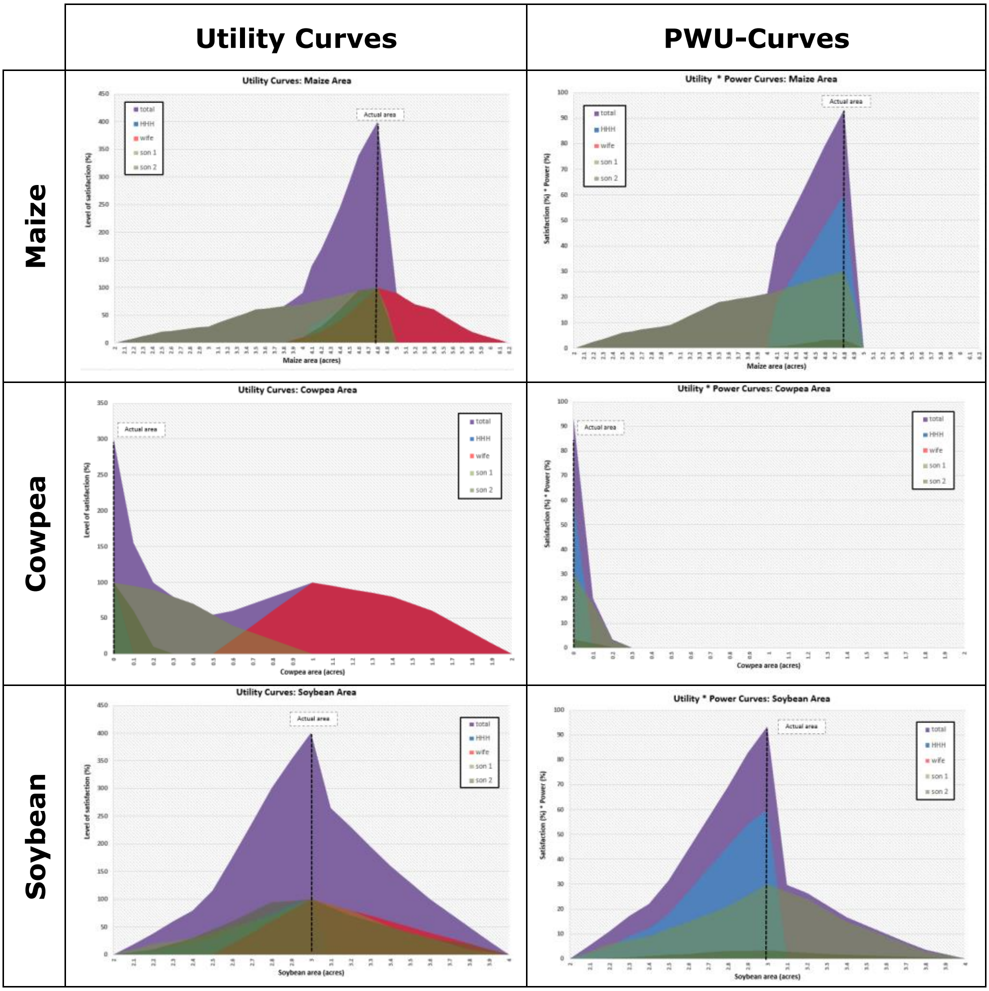


Figure 5.2. *Utility and power-weighted utility (PWU) curves revealing intra-household interests and power backings for a range of crop-specific land allocation options. Land use decisions in terms of crop areas (acres) are related to the level of satisfaction (0-100%) of individuals (HHH=blue, wife=red, sons = greens) and at household level (total=purple).*

The reasons for the minimum (η^2=0.230) and the maximum acceptable area (η^2=0.044) differed per crop (*cf.* Fig. A5.8, Annex 5H): securing a sufficient amount of food for home consumption was the most important aspect for cultivating a minimum area of maize, while a combination of covering household food needs and sustaining sales was the dominant reason for a minimum of cowpea, and sales the main reason for the soybean minimum area. Input costs were the main constraint in growing more maize, while labour availability was the main constraint for not cultivating more cowpea or soybean. Furthermore, we found a moderate trend of powerful (η^2=0.178-0.280) or male (η^2=0.099-0.11) respondents to have a greater interest in minimum sales than less powerful or female respondents, who were more concerned about minimum food needs. Concerning the shapes (*cf.* Annex 5B) of the individual utility curves, the convex (downwards) and the linear shapes were most prevalent on both curve sides (min-ideal, ideal-max). Annex 5I and 5J provide further information about curve shapes as well as crop-specific implications of areal changes.

5.2.3. Newtonian model

The Newtonian model accurately predicted 23% of the actual areas and correctly inferred the decision direction (±10%-margin) in 83% of the cases. The accuracy-check of the decision direction excluded cases with an actual area of zero and predicted area greater than zero, since the division by zero is undefined and a percentual margin could not be applied. The accuracy differed per crop, increasing from 15% to 92% in the case of maize and from 17% to 67% in the case of soybean, when allowing a 10% margin. For cowpea, the accuracy stayed at 33% due to many cases where no percentual margin could be applied.

To better understand the generally low predictive power of the Newtonian model, we examined all cases (n=15) where the divergence between actual area and predicted area was greater than 10% and where the percentual margin could not be applied. In 80% of these cases, despite divergent interests and a reportedly shared power distribution, the actual area corresponded forthright to the HHHs preference. However, for the disagreeing household members in 8 out of these 12 cases, the level of satisfaction at the predicted area would still be zero, implying no gain but rather a loss of time and efforts when engaging into a negotiation. In further 2 out of the 12 cases, disagreeing household members would lose satisfaction (-32% to -50%) at the predicted as compared with the actual areas. In the remaining 2 out of 12 cases, when shifting from the actual area to the predicted area, disagreeing household members (P=0.15) would gain 34% and 42% of satisfaction respectively, while other, more powerful household members would lose (-100%) or not gain any satisfaction, rendering the predicted area an unlikely and inefficient outcome at household level. Hence the lacking prospect for improvement seems to conclusively explain the power abstention of disagreeing household members in most (12/15) mismatching cases. The remaining three mismatches are shared by all three models and have likely been caused by an emotional bias in the survey responses of the most powerful household members, deploring resource constraints that compelled a last-minute areal reduction (*cf.* Annex 5K).

5.2.4. Comparison of model accuracy

The generic rule correctly indicated the actual area in 92.5% of the cases, excluding cases without disagreements. The generic statement hence was a slightly more reliable predictor of the decision-outcome than the utility-power model. Both, the generic decision rule and the utility-power model proved to be better predictors of decision-outcomes than the Newtonian model (*cf.* Fig. 5.3).

5.2.5. Utility of technical farm configurations

When interpreting the model-generated alternative farm configurations (N=850) as described in Michalscheck et al. (2018a) in terms of their utility to individual household members, we find that many or most model-suggested configurations for cowpea and soybean would be unacceptable to one or more household members and that the current configurations, among all options, perform best, with the exception of the baseline cowpea area being unacceptably small for the wife (Fig. 5.4).

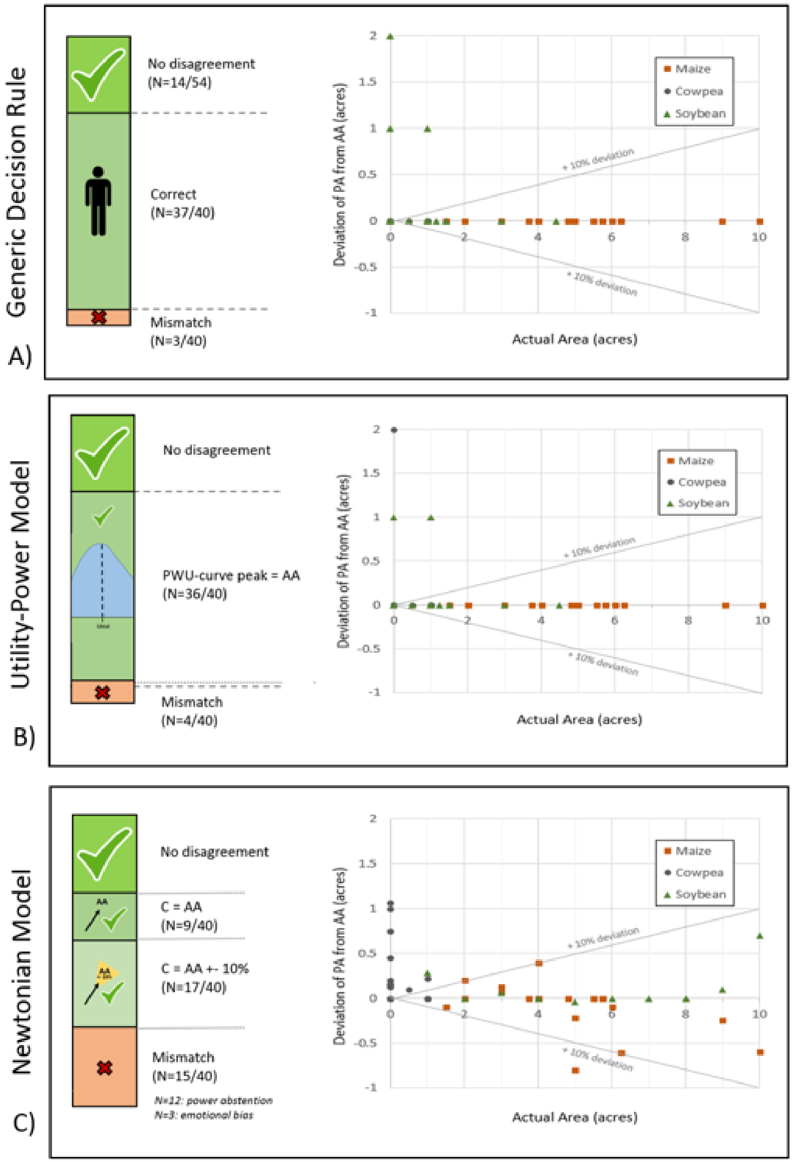


***Figure 5.3**. Comparison of model accuracies, defined as the share (n=x/40) of cases with disagreements, for which a model correctly indicated the actual area. The individual bar charts and scatterplots reveal the performance of (A) the generic decision rule, (B) the utility-power model and (C) the Newtonian model. The scatterplots illustrate the deviation between predicted crop areas (PAs) and actual crop areas (AAs) in acres per model in dependence of the AA.*

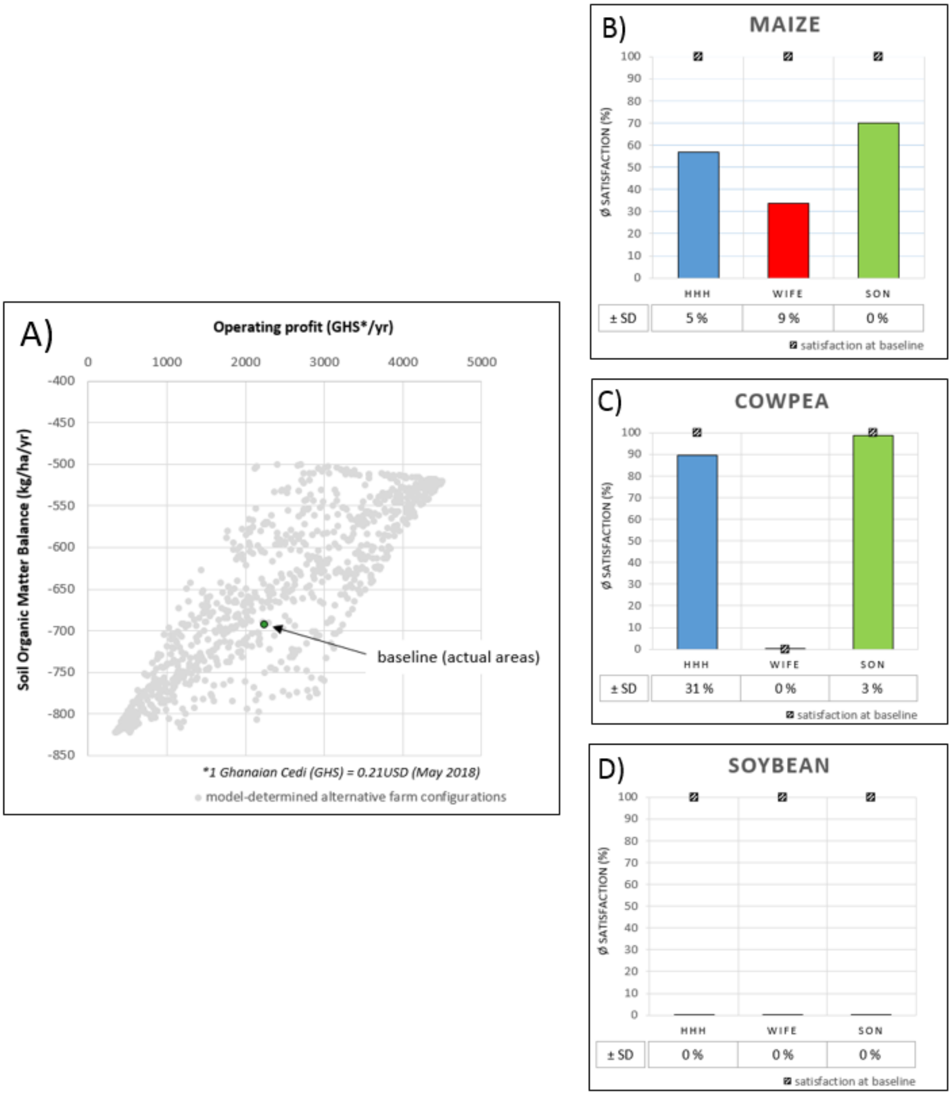


Figure 5.4. *Social viability of model-generated alternative farm configurations. A) Solution cloud of alternative farm configurations (N=850) for a medium resource endowed household in Duko. The configurations are displayed according to their performance in operating profits and the soil organic matter balance. The bars in B), C) and D) illustrate the average utility (satisfaction %) of the model generated alternatives. The black symbols indicate the individual's (HHH's, wife's, son's) utility at the baseline.*

5.3. Discussion

Our study demonstrates the feasibility and added value of jointly assessing interests and power positions to better understand resource allocation decisions within smallholder farm households. At the same time, our results raise the question as to why people report to hold power while their power share does not seem to have any impact on the final outcomes observed? Despite the reported multilateral power distribution, decision-outcomes in Duko seemed rather unilateral: in cases of intra-household disagreements, land allocation-decisions corresponded to the preference of one household member, mostly the powerful HHH (90%), instead of being a compromise between the prevailing different interests. The HHHs dominance in decisions on land allocation is also reflected in a higher average satisfaction level at the actual area for HHHs (96%) as compared to sons (75%) and wives (55%), implying social trade-offs at household level. The generic statement 'the HHH decides' hence served as the most accurate predictor of the actual area, apparently supporting studies that refer to generic decision rules (Akudugu et al., 2012; Ayamga et al., 2016; Djurfeldt et al., 2018; Paresys et al., 2018). We discuss three possible explanations for the invisibility of power shares.

(1.) People do not hold power

Respondents indicate to hold power, while, except for the HHH, they actually do not. This explanation is the most evident counterpart to the generic decision rule. Respondents may have consciously or unwittingly under- or overstated their own and other members' ability to influence decisions. While a certain desirability bias is likely (Alwang et al., 2017; Anderson et al., 2017; Fisher, 1993)*, the household power structure was unanimously described as 'multilateral' by 93% of the respondents and the independently reported power shares are, in our view, mostly too large and too congruent (cf. ØSDs in Fig. 5.1) to be waived aside as a bias (cf. Annex 5L)*.

(2.) 'Either-or' decisions

Respondents hold power, but the power is 'lost' if it does not contribute to the option with the largest power backing at household level. The decision is therefore not made considering the (continuous) range of land allocation options but rather between the (discrete) preferences of the most powerful respondents. The ideal area with the largest power backing at household level will be chosen, avoiding the emergence of a compromise. Disagreeing household members would hence simply be overruled. The 'either-or' explanation follows a similar logic as the highly accurate utility-power model, whose accuracy can be explained by the negligence of power shares that do not contribute to the option with the highest PWU. However, an argument against the 'either-or' explanation are the nuanced reports on power distribution: in a setting with only 'win or lose'-options, would one not expect actors to feel that they have either 'a lot of power' or 'no power at all' rather than indicating to hold intermediate power shares of e.g. 10% or 50%? We therefore think that this explanation is possible, but not entirely convincing.

(3.) People withhold power

Respondents hold power, but decide not to exert it (Rucker and Galinsky, 2017) e.g. when their prospective gain in satisfaction is too low. Power abstention plausibly explained most of the Newtonian mismatches, which resulted from the incorrect model assumption that all power shares were 'activated', influencing the decision-outcome. In contrast to the 'either-or' explanation, the theory of power abstention implies that people are not passively overruled, but that they actively withhold their power shares. The withheld power shares may still be relevant in time or across decision domains: a repeated power abstention may improve a persons' negotiation position for future decisions. Across decision domains, we may also encounter mechanisms of reciprocity (Brett and Thompson, 2016), so that if one person gets his/her will on one aspect, another person may consequently have a better position to claim his/her preference on another aspect. Although unlikely (cf. Annex 5K), the three model-

overarching mismatches may be expressions of power-claims in time or across domains.

Despite the unilateral decision-outcomes observed, we hence think that the reported power shares are meaningful, sometimes withheld or overruled, possibly with an importance in time and across decision domains. Further research is needed to shed light on the modes and implications of the invisibility of social power, answering questions like: how do actors define and determine their power base, means and magnitude (Dahl, 1957)? Are actors being overruled (passive) or do they withhold power (active mode)? What are the circumstances and implications of one or the other mode *e.g.* what is the minimum gain in satisfaction and what is the maximum power difference in order for an actor (*e.g.* a household member) to engage into a negotiation? For as long as these questions are unresolved, we think that an elementary piece of information is missing in debates on women empowerment in agriculture (Alkire et al., 2013; Karlan et al., 2017; Malapit and Quisumbing, 2015; O'Hara and Clement, 2018), too. Beyond scrutinizing our interpretation of recorded power shares, we need to critically review our measurements of 'individual interests', too: every act of communication has a content and a relationship aspect (Watzlawick et al., 1967). The separate and confidential inquiry about individual interests invited the respondents to put aside the relationship aspect, while relationships, *e.g.* relative power distribution, do play a role during the actual negotiation. Despite our attempt to focus on individual positions, household members, particularly those with a weak power position, may internalize the opinion of powerful household members, even when asked about their own interest, not truly revealing their personal standpoint. We suspect that interests might be more dissimilar than our data suggests, hence we consider our study to provide a conservative impression of the dissimilarity in intra-household interests. We furthermore see the need to explore the interrelatedness of crop—specific decisions *i.e.* the consequences of a simultaneous increase or decrease of various crops on the respondents' minimal and maximal areas as well as reported land use implications.

Concerning flexibility in negotiations on land allocation, we found that the higher a households' resource endowment and the smaller the power share of a respondent, the greater his or her flexibility. Flexibility, for respondents with low power shares, holds the advantages of (i) increasing the individual satisfaction with relatively uncontrollable decision-outcomes and (ii) attenuating possible conflicts, thereby also reducing personal losses (Druckman, 1993; Payne et al., 1993). Greater flexibility associated with higher resource endowment may be explained by the larger 'room to manoeuvre' at farm level (Michalscheck et al., 2018a), implying new opportunities but also the need for collaboration, especially on household labour allocation associated with a larger farm. Regarding the utility curve shape, in line with Vendrik and Voltjer (2007), we found that most utility curves evince a convex (downwards) or a linear shape, indicating the maintenance of a high level of satisfaction around- and diminishing marginal utilities towards the ideal areas (Kubanek, 2017).

Concerning the utility levels associated with technically promising farm configurations (*cf*. Fig. 5.4), our results demonstrate the importance of comprehensively assessing the social viability of technically promising resource allocation options. (Participatory) simulation modelling efforts may now be extended by scenarios that maximize household-level utility or minimize individual trade-offs. Surely, the alternative farm configurations entail many other characteristics and decisions than just those concerning land allocation to maize, cowpea or soybean. Nevertheless, unacceptability on one aspect may render a technically brilliant farm configuration partially or fully unviable. To R4D projects interested in exploring the likelihood and the social implications of a given change, we hence recommend a look beneath the social surface of households: a generic decision rule may serve as a good first proxy of power distribution. The utility-power model holds the advantage of being accurate and able to reveal social trade-offs. Due to its 'either-or' mode we expect the utility-power model to also perform well for decisions with discrete options such as the selection of a particular crop, cultivar or technology package. The utility power model may also be used to assess decision-making dynamics at higher institutional or administrative levels *e.g.* land allocation options at community or regional level (Djaenudin et al., 2016; Marcos-Martinez et al., 2017; Ou et al., 2017; Santé and Crecente, 2007; Sharawi, 2006; Su et al., 2018). Imperatively, the more household members or stakeholders are consulted, the deeper the insight into decision-making dynamics and social trade-offs. If time and budget constraints compel a limitation, the consultations may be limited to the core stakeholders. For household-level research in Northern Ghana, we recommend to, at least, consult the HHHs, the wives and the oldest sons or daughters individually, constituting the social fundament of most local households (Michalscheck et al., 2018a). The Newtonian model proved to be mainly of conceptual value. However, if the mode of power abstention is scrutinized and better understood, the Newtonian model may turn into the most accurate representation of and predictive model for decision-making processes at household level.

5.4. Conclusion

Global research efforts to identify sustainable resource allocation options for multi-agent systems must consider social trade-offs and power dynamics in order to understand how change comes about and what it means for all parties involved. Our Ghanaian case study revealed significant intra-household trade-offs in land allocation decisions, invisible to any project evaluating change exclusively at farm-household level. Furthermore, the mismatch between 'ascribed power' and 'exerted power' suggests that power shares may be actively withheld or overruled, despite the male household heads' apparent dominance in decision-making. We recommend the joint application of a local generic decision rule and the utility-power model to combine simplicity with a detailed insight into individual and household-level utilities. Insight into individual utilities allows diving beneath the household's social surface, identifying technical options that maximize household-level utility and minimize individual trade-offs, therewith identifying direly needed, socially (more) viable resource allocation scenarios as part of our global efforts towards more sustainable social-ecological systems (Ostrom et al., 2007).

Chapter 6

6. Simulation of an actual negotiation

Based on:

Michalscheck, M., Groot, J.C.J., Fischer, G. and Tittonell, P.A. Serious gaming to uncover dynamics in farm land allocation decisions at household level in Northern Ghana.

Submitted

Abstract

Globally, 83% of all farms are smallholder farm systems, whose livelihoods depend on effective land management and allocation. While land is typically cultivated by the various members of a farm household, land allocation decisions depend on the approval, the ambition and the abilities of influential household members, likely affecting all other household members, too. While intra-household decision-making processes have been described to depend on the interplay of prevailing interests and power positions, so far knowledge on interests and power positions is based on individual reports rather than actual observations. With the aim to explore the process of land allocation in a socially complex smallholder farm system, we invited members of a smallholder community in Northern Ghana to join a closed, experimental serious game, simulating a negotiation process between a male household head (HHH), a wife and the eldest son of a hypothetical local farm household. While the HHH was the key decision maker acting as a strategic gatekeeper in a funnel-like process, the wife and the son had a significant influence on 'his decision' *i.e.* the household-level negotiation outcome. Model-based analysis showed that the household-level outcome was more profitable as well as agro-biologically and nutritionally more diverse and productive as compared to the HHHs' suggestion. Power was observed to be actively deployed, withheld or passively overruled depending on decision domains and process dynamics. We observed an integrative negotiation style, resulting into high levels of satisfaction with the negotiation process and outcome by all parties, who reported a high level of similarity between simulated and real-life negotiations. The proposed game proved to be a culturally adequate, simple, cost and time effective tool to explore dynamics and intra-household perspectives on local resource use, fundamental for research on more sustainable socio-ecological systems.

Keywords: decision-making; gender relations; smallholder; sustainable resource management

6.1. Introduction

Globally, climate change (IPCC, 2014), population growth and the increasing land pressure call for more productive yet more resilient and sustainable farm systems (Bren d'Amour et al., 2017; Rasmussen et al., 2018; Tilman et al., 2011). Worldwide, 83% of all farms are smallholder farm systems (Herrero et al., 2017), whose livelihoods strongly depend on effective land management and allocation (Bren d'Amour et al., 2017; Rasul and Thapa, 2004; Tittonell et al., 2015). In smallholder farm households, functioning much like multi-stakeholder institutions (Haddad et al., 1997; Kabeer, 1994), land allocation decisions depend on the approval, the ambition and the abilities of influential household members, likely affecting all other household members, too (Agarwal, 1997; Doss, 2001; Michalscheck et al., 2018a). While intra-household decision-making processes have been described to depend on the interplay of prevailing interests and power positions (Haddad et al., 1997; Kusago and Barham, 2001; Michalscheck et al., 2018a; Padmanabhan, 2011; Purnomo et al., 2005; Schwilch et al., 2012), so far knowledge on interests and power positions is based on individual or joint reports by husband and wife (Becker et al., 2006; Browning et al., 2013; Doss, 2013; Elias, 2015a; Mwungu et al., 2017; Ngigi et al., 2017; Prabhu, 2010; Thomas, 1990) rather than observations on the actual interplay.

The actual interplay of interests and power positions on complex decisions in multi-stakeholder settings may be observed by means of serious gaming: in the natural resource management (NRM) context, serious games have mostly been used as an educational tool (Ansoms et al., 2015; Crovato et al., 2016; Gugerell and Zuidema, 2017; Hartig et al., 2010; Heinonen et al., 2017; Mayer et al., 2004; Merlet et al., 2018; Morganti et al., 2017; Onencan et al., 2016; Orland et al., 2014; Ouariachi et al., 2017; Salvini et al., 2016; Schulze et al., 2015; Tanwattana and Toyoda, 2018; Wang and Davies, 2015) or to facilitate consensus among stakeholders with conflicting or ill-defined interests (Craven et al., 2017; Hertzog et al., 2014; Magombeyi et al., 2008; Meinzen-Dick et al., 2018). In agricultural systems research, serious games have been employed for education and co-design (Ditzler et al., 2018), but, to our knowledge, only two studies explored intra-household decision-making (Ashraf, 2009; Iversen et al., 2006) using experimental economic games to test investment decisions of spouses in Uganda and the Philippines, respectively.

With the aim to explore the process of land allocation in a socially complex smallholder farm system (Doss, 2001), we invited members of a smallholder community in Northern Ghana to join a serious game, simulating a negotiation process between a male household head, a wife and the eldest son of a hypothetical local farm household. To better understand decision-making dynamics and to compare individual visions for land allocation with the household-level decision-outcome, we addressed the following five research questions (RQs, the addition '6' differentiates the RQs of Chapter 6 from the specific RQs of the overall thesis):

RQ6.1: How do (a) interests and (b) power positions differ among household members?

RQ6.2: How do individual interests and power positions shape household-level decisions?

RQ6.3: Can we observe trades (since person A gets crop X, person B gets crop Y) or power modes *i.e.* power being deployed, withheld or overruled?

RQ6.4: How does the simulated process compare with real-life negotiations on land allocation?

RQ6.5: How do the individual preferences on land allocation and the household-level decision-outcome compare in terms of the nutritional yield (food production), their economic (profitability), environmental (soil organic matter) and social (labour input) performance?

After introducing the case-study community and game methodology, we present and discuss the game process and results as well as the implications of our findings for ongoing research and projects that aim to bring about positive change in smallholder farmers lives.

6.2. Methods

6.2.1. Case-study site description

Duko (9.56° N -0.83° W) is a Dagomba smallholder farm community located in the Northern Region of Ghana, *cf.* Figure 6.1. Located in the Guinea Savannah agro-ecological zone (FAO, 2005), Duko is characterized by a unimodal rainfall regime with 1000-1200 mm of precipitation per year, with farmers practicing rainfed agriculture. Duko hosts 54 smallholder households, which are mostly large, male headed and polygamous, adhering to Muslim religion. Farmers in Duko grow cereals (maize, rice, millet), tubers (yam, cassava, sweet potato), legumes (cowpea, soybean, groundnut, bambara bean) and dry season vegetables (tomato, okro, chili pepper, green leafy vegetables). Farmers also own cattle, donkeys, small ruminants and poultry, depending on their resource endowment. According to the locally prevailing patrilineal customary law (Aryeetey et al., 2007; Lambrecht, 2016), household heads (HHHs) are the owners of farm land (Abdulai, 1986; Padmanabhan, 2007). HHHs are responsible for the households' food security, growing staple crops (maize, yam), while the wives are responsible for providing nutritional diversity, growing soup ingredients like groundnuts and vegetables (Apusigah, 2009; Padmanabhan, 2007). Despite their agricultural activities, women in Duko are described as traders rather than farmers. Being the future heir of land, the eldest son of a household enjoys particular respect (Abdulai, 1986; Apusigah, 2009). Sons are described as being interested in growing cash crops (rice, cowpea) to enable higher education or marriage (Iddrisu Baba Mohammed, 2016: *pers. comm.*). Upon marriage, the sons' wife or wives move into their husbands' compound, becoming part of the existing large household.

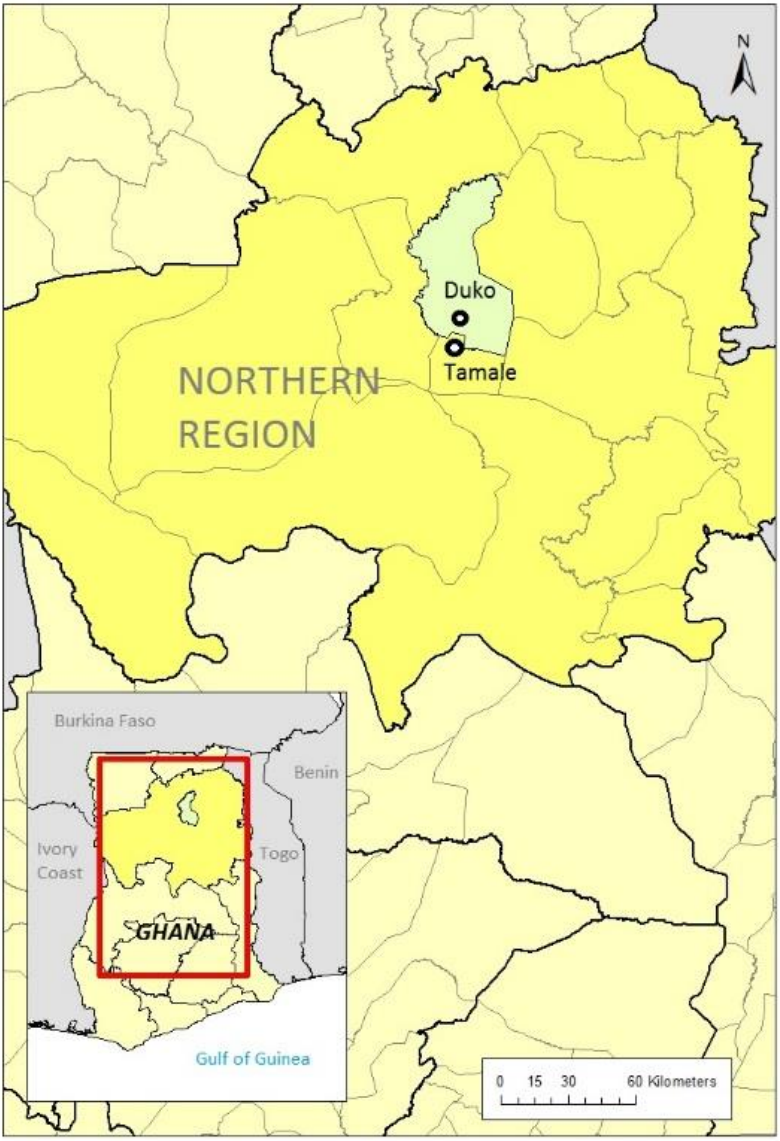


Figure 6.1. *Map of case-study site location. Duko is indicated by a symbol within the Savelugu-Nanton district, highlighted in green. Tamale, the capital of the Northern Region, highlighted in yellow, is marked with the second symbol underneath.*

While the household jointly works on the HHHs fields, wives and sons may cultivate individual fields (Apusigah, 2009; Lambrecht, 2016; Michalscheck et al., 2018a), too. To cultivate an individual field, a household member needs to ask the HHH for permission of use. If granted, cultivating an individual field implies autonomy on the crop choice, on the use of crop products and associated revenues from sales.

6.2.2. The game

A serious game (Abt, 1970) is a structured process, engaging stakeholders to operate in a simulated situation. The simulated situation typically evinces a goal, rules, competitive elements and feedback loops (Ritterveld et al., 2009). While many serious games aim to train or educate participants (Cai et al., 2017; Dörner et al., 2016; Michael and Chen, 2005), we aimed to carefully uncover and learn about household-level decision-making dynamics, namely the interplay of different interests and power positions concerning land allocation. The game set up was derived from narratives of real-life land negotiation processes in Duko (Michalscheck et al., 2018b). Game participants were invited to imagine being part of a well-defined medium resource endowed (MRE) farm household in their own community (Michalscheck et al., 2018a), facing the question which crops to grow on how much of the available farm land. We defined the demographic composition (9 members), the quantity (10 acres) and location (upland, valley and transition zone) of farm land, possible crop choices, animal types and numbers, availability of hired labour, private means of transportation and off-farm income. Despite describing a typical polygamous household with several wives, sons and adult daughters, the game was played with only the HHH, one wife and one (eldest) son, leaving it up to the participants to represent all members of their category or merely themselves. In separate groups, male HHHs, wives and sons were asked to develop a suggestion for land allocation. Each groups' interests, based on the group-level suggestions, were then represented by a spokesperson during the simulation of a household-level negotiation, pursuing the general games' goal of reaching household-level decision on land allocation. After observing or experiencing the negotiation, each participant was furthermore invited to provide feedback on the negotiation process and outcome.

Our game may be classified as a closed (Bousquet et al., 2002; Falk and Heckman, 2009; Janssen, 2010), experimental (Redpath et al., 2018) game *i.e.* allowing a finite combination of fixed elements (crop cards) to be allocated on a pre-defined land area. Conducting this experimental game with real stakeholders increased the likelihood of our results being informative about real-life negotiations (Redpath et al., 2018). However, with stakeholders being members of the same community, our first priority in game design was to guarantee a safe sphere for all game participants to fully engage.

The social set-up

According to numerous (N=58) independent narratives of household members (Michalscheck et al., 2018b) and local elders (Iddrisu Baba Mohammed, 2016: *pers. comm.*), intra-household decision-making processes in Duko are largely kept private. Land allocation decisions were reported to be typically made during a household gathering, organized by the male HHH who summons the (core) household members to inform them about his decision or to discuss possible land allocation options for the upcoming season (Michalscheck et al., 2018b). In order to diminish biases and conflict potential, we worked with three groups of about five participants of different and differently endowed households. Resource endowment was defined according to the locally validated farm typology of Michalscheck et al. (2018a). While household resource endowment was a selection criterion for participants, during the game, participants were grouped according to their intra-household position, so that each participant joined his or her 'own group' *i.e.* the group of HHHs, wives or sons. We chose these three particular stakeholders since the community had symbolically compared the HHH, the wife and the eldest son or daughter to the three stones under a cooking pot *i.e.* the social fundament of a local farm household (Kuivanen et al., 2016b; Michalscheck et al., 2018a).

Game preparation

In preparation of the game, three facilitators were trained, participants were invited, the game scheduled and gaming materials prepared. Before the start of the game, participants were registered with their name, gender and household-level information, to determine their intra-household position and household resource endowment.

The four phases of the game

The game itself was split into four consecutive phases:

1. Game introduction
2. Group discussions
3. Household-level negotiation
4. Debriefing

1. Game introduction

During the introduction, the game's purpose and set-up were explained to all participants (*cf.* Annex 6A). We then described the farm household that the participants should imagine to be part of (*cf.* Annex 6B). Furthermore, the groups were briefed on the procedure of the subsequent individual group discussions, *cf.* Annex 6C.

2. Group discussions

Each group met at a different location with the task to describe their own production orientation and interests, suggesting a farm land configuration that was, in their view, a suitable compromise between the household needs and their own interests. We hence did not obtain isolated individual preferences, but individually shaped suggestions for a household-level solution. Each group was, moreover, asked to elect a spokesperson: the spokesperson was not allowed to participate in the actual discussion within the group, but he or she had the role of a mediator, summarizing the different opinions or joint conclusions and leading the group towards a consensus. The spokesperson was the only group member joining the negotiation, representing the opinion of the group. The election of a spokesperson was meant to hinder individual participants from dominating the discussion and the negotiation, allowing greater wisdom to emerge from the principally diverse groups (Klimoski and Ash, 1974). Each group was accompanied by a facilitator, who was able to re-explain the game elements, ensured that the spokesperson did not participate in the discussion, who recorded the group-level final decision and went through a list of pre-defined questions on the groups' land allocation suggestion. The questions and template for capturing the group-level consensus are provided in Annex 6D.

3. Household-level negotiation

Three household members, each represented by the spokesperson per group, were asked to engage into an actual negotiation in order to reach a household-level consensus. The spokespersons were not informed about each other's group-level discussions or result. There were no rules or restrictions for the negotiation. The sole goal defined was to reach a household-level agreement on the farm land configuration. All other participants were asked to witness the negotiation without interfering. The negotiation was filmed and translated and is provided in Annex 6E. The household-level result was captured and the three negotiators were asked to explain the functions of the chosen cropping pattern.

4. Debriefing

To capture the participants' satisfaction with and evaluation of the negotiation process as well as the outcome and to understand how the negotiation was different from negotiations in their own household, the three facilitators consulted each participant separately and confidentially. We used the stick-score method proposed by Michalscheck et al. (2018b) to capture the level of satisfaction and the observed power distribution among the negotiators. The debriefing protocol is provided in Annex 6F.

All qualitative and quantitative results were transcribed and are presented in Annex 6G-K. To model and calculate the performance of the intermediary and final land allocation decisions, we recombined crop and livestock data of Michalscheck et al. (2018a).

6.2.3. Data analysis

We answered most research questions by describing the participants' self–reports on interests (RQ6.1a and RQ6.5), power shares (RQ6.1b) and similarity to real-life negotiations (RQ6.4). To complement the self-reports, we used methods of interaction analysis (Bales and Cohen, 1979; Dabbs and Ruback, 1987; Moritz and Corsten, 2018), analysing the video material in terms of the contentual contributions, body language and interactions including shares and sequence of speech, interruptions and disagreements during the negotiation. In line with the standards of Social Network Analysis (Balkundi and Kilduff, 2006; Durland, 2006), the frequency, direction and the duration of interactions between the three negotiators were interpreted as a snapshot of actor centrality as well as the in- and out-degree of information flow. The results were visualized in a social network diagram (Borgatti et al., 2009). Greater shares of speech as well as strategic and longer speech sequences (Falzon et al., 2018) were taken as an indicator of power (Balkundi and Kilduff, 2006). Interruptions were hypothesized to indicate dominance while being interrupted was interpreted as an external non-recognition of dominance (Okamoto et al., 2002; Weatherall and Edmonds, 2018). We also analysed the deployment of interruptions, recording *e.g.* whether they served to accelerate a clarification or to demonstrate power hierarchies.

Concerning the body language, we analysed the participants' posture, facial expressions, voice and gestures for signs of confidence, comfort or hesitation and discomfort (Metallinou et al., 2013; Van den Stock et al., 2008). We assumed that power positions are partly embodied, with powerful participants being more likely to speak with a strong and clear voice, strict or relaxed facial expressions and an upright or relaxed posture (Thomson, 2017) while less powerful participants are more likely to evince a crouched body posture, to use a less strong voice, to show face or body tension and to avoid direct eye contact. The body language was interpreted with the support of local academics. The contentual contributions during the negotiation were analysed to evaluate how well each spokesperson represented the interests of his or her group. Contentual congruence was assessed by comparing targeted, claimed and obtained amounts of land per crop and per household member. We also asked for an evaluation (0-100% satisfaction) of the spokespersons' performance as part of the debriefing, checking whether the participants felt accurately represented during the negotiation. Based on a mismatch between reported and executed power shares, Michalscheck et al. (2018b) had hypothesized that the execution of power was optional and not necessarily always successful *i.e.* power could be actively deployed, withheld or passively overruled. There may also be trades between household members to each get one's will on at least one domain instead of aiming at compromises in all domains. The interaction analysis was furthermore used to search for evidence on the different power modes and trades (RQ6.3). The whole-farm performances were modelled based on records of the intermediary and final land allocation decisions (RQ6.5).

6.2.4. Whole-farm modelling

We used the whole-farm model FarmDESIGN to determine and compare the intermediary and household-level decisions in terms of the nutritional yield (kcal and nutrients/person/yr), operating profits (GHS/yr), the soil organic matter (SOM) balance (kg/ha/yr) and the required labour inputs (h/yr). Profits, SOM balance and labour inputs represent the economic, environmental and social sustainability dimension of the farm respectively and have been recognized as important farm objectives by farmers in Duko (Michalscheck et al., 2018a). The nutritional yield *i.e.* the raw energetic (kcal) and nutritional output, are novel additions in the whole-farm comparison of Ghanaian farm configurations (Michalscheck et al., 2018a). Nutrition was included since food production for home consumption was independently mentioned as the most important farm objective by all three stakeholder groups during the game. Beyond the farm-household-level performance, we assessed the intra-household implications per land allocation scenario by comparing the profitability of individual fields (wife and son) and gendered (male and female) labour inputs.

FarmDESIGN is a static, bio-economic model, allowing a detailed analysis of the farm performance and resource flows (Groot et al., 2012). The model describes a farm system in terms of its productive resources (land, livestock, crops), inputs (operating costs, labour input, fertilizers, crop protection products, seeds *etc*.) and outputs (income, crop and livestock products). Despite our game being focused on land resources, a typical smallholder farm household in Duko owns animals, too, which have to be fed and whose manure, in turn, serves as fertilizer for the crops. FarmDESIGN integrates crop and livestock components, making it particularly suitable for modelling mixed crop-livestock systems like our case-study farm. The FarmDESIGN models can be downloaded as part of the supplementary materials (Annex 6L). All data underlying individual models are explained in the respective FarmDESIGN notes, accessible via the model user interface.

6.3. Results

6.3.1. Participant demographics

The game was played with six HHHs, five wives and five eldest sons. Figure 6.2 illustrates the participants' age structure and household resource endowments. Seven of the sixteen participants were associated with MRE households, being the game's target farm type.

6.3.2. Individual interests (RQ6.1a)

Individual interests are embedded in overall production objectives, translating into crop choices and associated land sizes. HHHs, wives and sons independently mentioned the same two main production objectives: food provision for home consumption and income generation to cover school fees as well as health expenses. Wives and sons, however, envisioned a farm configuration that was agro-biologically much more diverse than the HHHs suggestion, with nine instead of five different crops, *cf.* Figure 6.3.

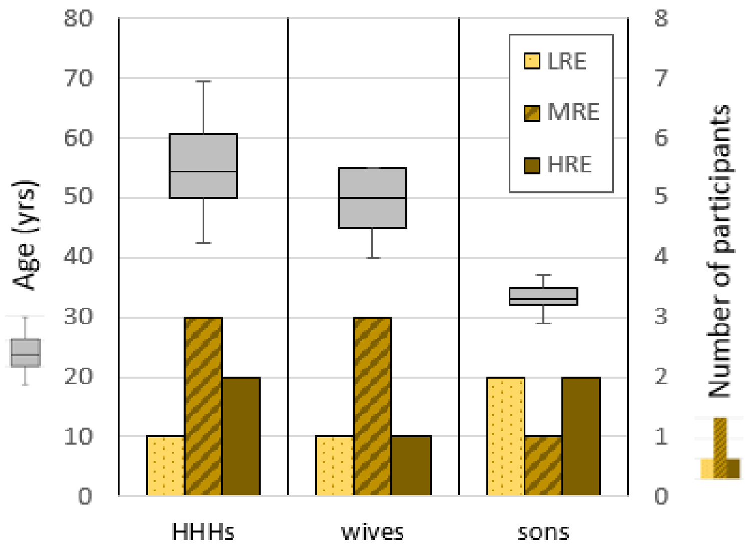


Figure 6.2. *Age and farm resource endowment of household heads (HHHs), wives and sons participating in the game. The whisker-plots indicate the age distribution of participants. The bar charts indicate the number of participants per farm type as defined by low, medium and high resource endowment (LRE, MRE and HRE).*

The HHHs chose the largest maize area and the wives the largest groundnut area, both crops being central food and cash crops. HHHs, wives and sons envisioned the same amount of land for soybean (cash and food), rice (cash) and yam (food and ceremonies). Sons and wives also had congruent suggestions concerning the amount of land for vegetables and sweet potatoes (food and cash) and they were the only members interested in growing cowpea (food and cash) or millet (food and rituals) respectively. The wives envisioned the greatest amount of individual land (3.5 acres), followed by HHHs (2.5 acres) and sons (1.5 acres). While the wives and HHHs allocated individual fields to wives and sons, the sons only allocated individual land to themselves, not to the wives. The sons assumed the wife’s needs to be satisfied from ‘household production’ rather than from own fields.

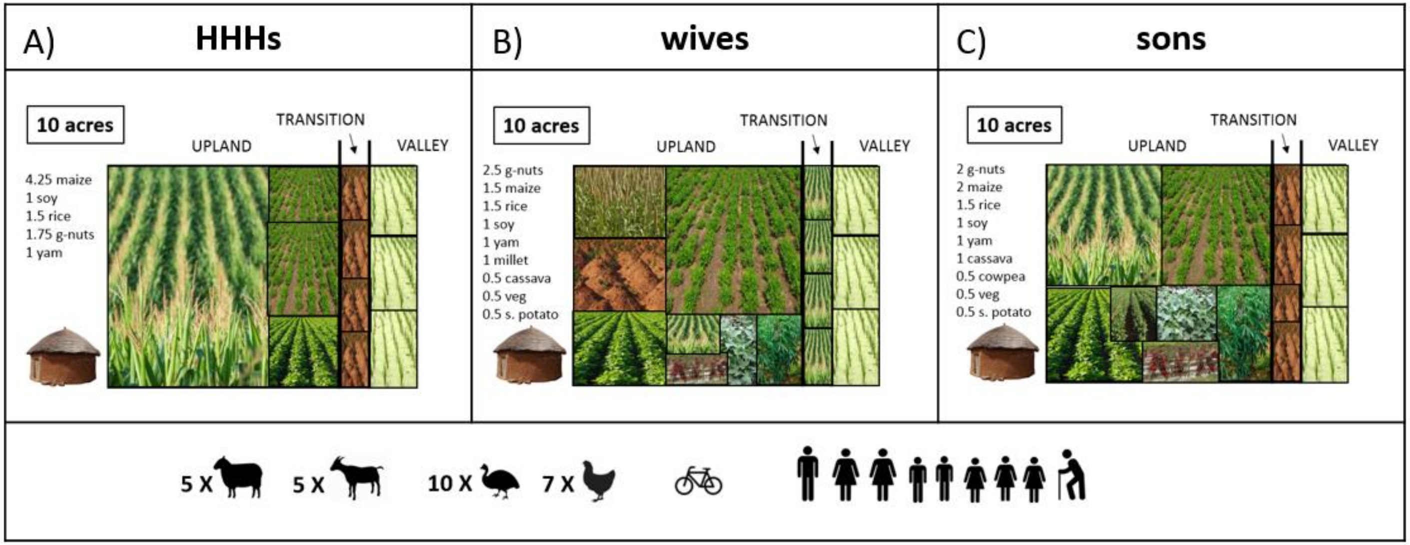


Figure 6.3. *Suggested land allocation per stakeholder group of A) HHHs, B) wives and C) sons, based on shared assumptions on household composition and resource endowment.*

While our notes do not suffice to judge the level of intra-group disagreement, all participants reported high levels of satisfaction with the spokespersons, seemingly indicating shared convictions at group level.

While individual interests were captured before the negotiation, the power evaluation was performed afterwards. Therefore we first present a basic description of the negotiation process and results (RQ6.2) before reflecting on power shares (RQ6.1b).

6.3.3. Household-level negotiation (RQ6.2)

The negotiation process was characterized by a high level of mutual respect, support, active listening and curiosity about each other's perspectives. Individual suggestions were put forward in a concise, transparent, well-structured and determined manner, albeit the wife and the son showing reservations particularly in the beginning of the negotiation process. The three negotiators seemed to take the game seriously, being emotionally involved and displaying a high level of identification with their roles.

Concerning the outcome, the household-level land allocation decision comprised 4 acres of maize, 1.5 acres of rice, 1.5 acres of groundnuts, 1 acre of soybean, 1 acre of cassava, 0.75 acres of yam and 0.25 acres of vegetables. The son received 1 acre to grow groundnuts and 0.5 acres to grow rice. The wife obtained 0.5 acres of groundnuts and maize each. All three spokespersons argued in line with their respective groups' mandate but had to make compromises (*cf.* Table 6.1).

Table 6.1. *Comparison of crop-specific individual land allocation suggestions and the household-level result. The table lists the individual target amount of land (acres) as well as the deviation (Δ) from the household-level decision.*

	HHHs		**Wives**		**Sons**		Household-level result (acres)
Crop	target (acres)	Δ	target (acres)	Δ	target (acres)	Δ	
Maize	4.5	-0.5	1.5	2.5	3	1	4
Millet	0	0	1	-1	0	0	0
Soybean	1	0	1	0	1	0	1
Cowpea	0	0	0	0	0.5	-0.5	0
Rice	1.5	0	1.5	0	1.5	0	1.5
Yam	1	-0.25	1	-0.25	1	-0.25	0.75
Cassava	0	1	0.5	0.5	1	0	1
Vegetables	0	0.25	0.5	-0.25	0.5	-0.25	0.25
Groundnuts	2	-0.5	2.5	-1	1	0.5	1.5
Sweet potato	0	0	0.5	-0.5	0.5	-0.5	0
Total deviation		2.5		6.0		3.0	

The wives made the largest compromise in terms of deviations between targeted and obtained areas, with a sum of deviations of 6.0 acres, while the summed deviations for HHHs and sons were 2.5 and 3.0 acres, respectively. The comparison between targeted and obtained areas reveals that the HHH largely got his will on the area of maize and sweet potato, the son got his will on the area of cassava, together the HHH and the son got their will on the millet- and together the HHH and the wife got their will on the cowpea area. The crops of sweet potato and cowpea were not discussed during the negotiation, while millet was designated to be grown as an intercrop.

Game participants reported to be highly satisfied with the decision-outcome as well as the performance of the spokesperson. Concerning the decision-outcome. HHHs indicated a satisfaction level of 83%, the wives of 94% and the sons of 90%, resulting into a total average satisfaction of 88%. For the performance of the spokesperson, the HHHs indicated a satisfaction level of 78%, the wives of 98% and the sons of 90%, resulting into a total average satisfaction of 88%.

6.3.4. Power shares (RQ6.1b)

Game participants evaluated the HHH to be most influential with 74% of the total power, followed by the wife (14%) and the son (12%), based on the intersectionality of his age, sex and birth rank. The power shares in the game were similar to those reported for real-life negotiations (Fig.4). For both, simulated and the real-life negotiations, each group provided the highest mean evaluation of their own power share among all groups. For real life negotiations, HHHs and sons both thought that the wife and the son had equal power shares.

We analysed the video material to detect additional clues on power distribution among the negotiators.

The sequence and shares of speech (*cf.* Fig. 6.5A and 6.5B) revealed that the HHH held a dominant role, leading the process and holding a speaking share of 50%.

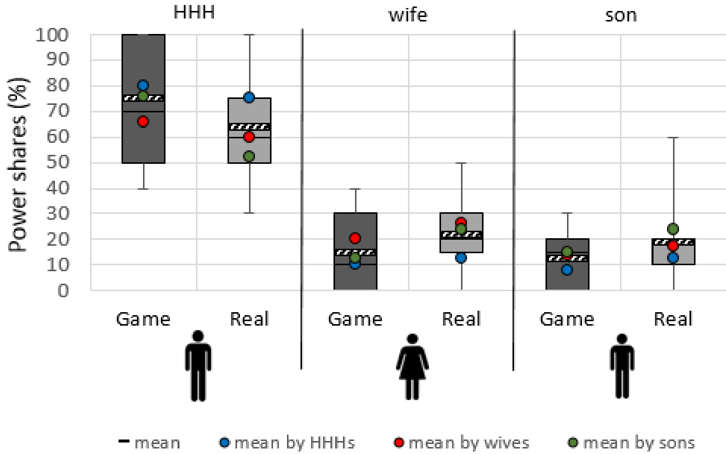


Figure 6.4. *Estimated power shares for the HHH, the wife and the son as observed during the game ('Game') and as reported for real-life ('Real') negotiations by the participants (N=16), referring to their own households.*

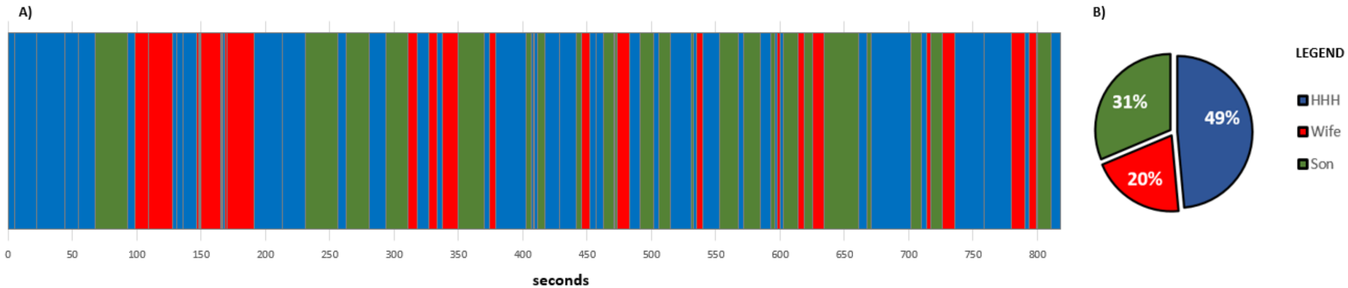


Figure 6.5*. Speech A) sequence and B) shares (%) per negotiator.*

While the wife, upon direct invitation of the HHH, put forward her interests at the beginning of the negotiation, her later interventions were rather short and targeted. The son seemed to restrain himself at the beginning of the game, getting more active with suggestions and competing with the HHH for the moderators' role as the game proceeded.

Concerning the interaction of the spokespersons, the HHH evinced a high betweenness centrality, being the centre of communication: the HHH spoke most and most frequently (*cf.* Fig. 6.6). The wife and the son addressed their interests to the HHH, not to each other, except towards the end of the game. Concerning the in-degree frequency of 'being addressed, the negotiators evinced almost equal counts, but the HHH received most (time and frequency) individual information.

Concerning interruptions (N=11), the son interrupted least and was most interrupted. The HHH interrupted most and was interrupted thrice. The wife interrupted the HHH once and the son twice, but was interrupted only twice by the HHH. About half (n=5) of the interruptions served to clarify a situation, while the other interruptions were interpreted as competition for process leadership, overruling a speaker to bring forward one's own point of view earlier or louder, not necessarily expressing conflicting interests or contrasting views.

Concerning disagreements, in three out of six cases the HHH got his will, the son and the wife each got their will once, and the remaining case was abandoned since the negotiators realized that they did not need to decide on the allocation of intercrops in the game. In addition to open disagreements we observed instances of conscious disregard *e.g.* several propositions of the son directed to the HHH were ignored or overruled by a suggestion from the HHH. We interpret conscious disregard as an attempt to limit or lower the claimed power standing of the opponent.

When analysing the negotiator's contentual contributions we, furthermore, observed the HHH to invent circumstances (*'Last year we grew...'*), favouring his position.

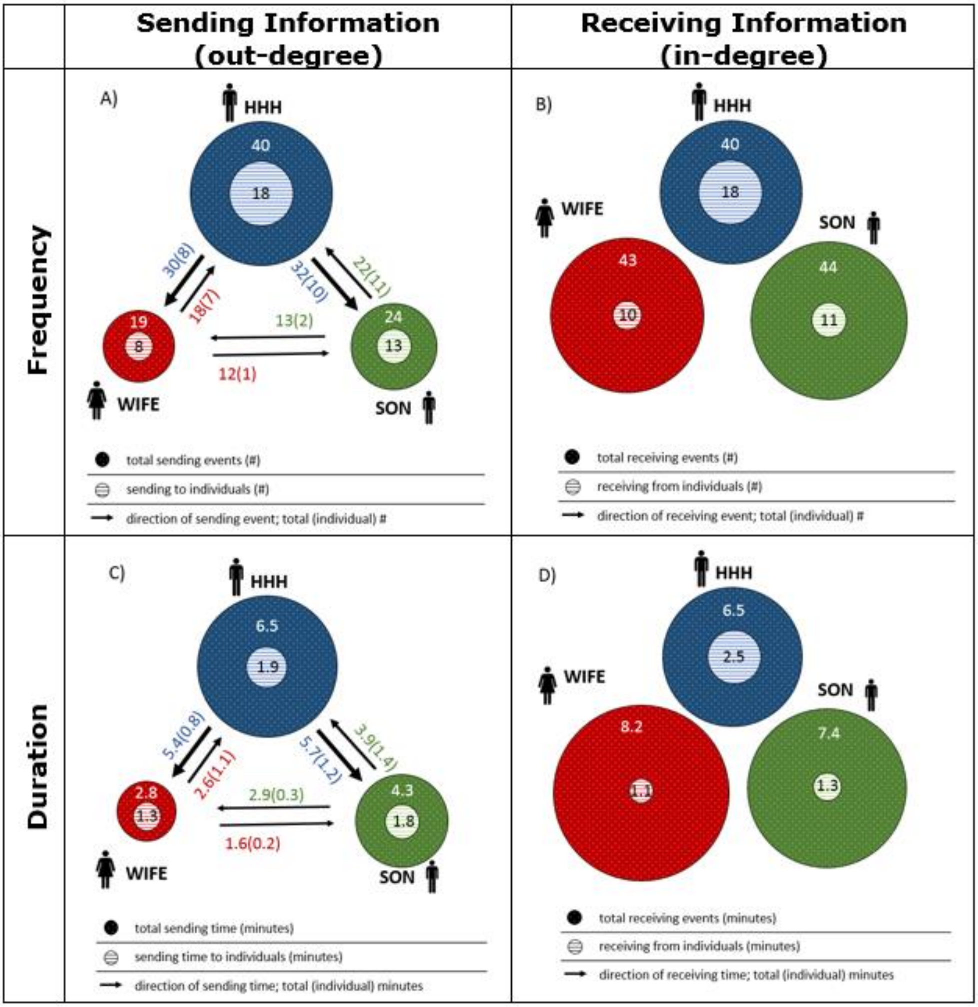


Figure 6.6. *Socio-gram showing the frequency (A, B) and duration (C, D) of interactions between the HHH (blue node), the wife (red node) and the son (green node) during the negotiation. The node sizes are proportional to the in- or out-degree of information flows, with node-numbers expressing the frequency or duration (in minutes) of sending (A and C) or receiving (B and D) events. The arrows in A) and C) indicate the direction of the total (and individual) sending events.*

The invented arguments fit into the general storyline of the game and were difficult to challenge since contesting them would have questioned the players' authority in and possibly beyond the game. Not questioning an argument, however, strengthened the players' authority through the ability to shape the game elements and boundaries.

The body language of the HHH was perceived as relaxed, confident and attentive. However, at times, it seemed as if he had difficulties to simultaneously act in his two roles: the self-assigned role as a mediator gave him authority but seemed to weaken his capacity to react to game dynamics as a HHH, putting forward his individual interests. The son started the game in a submissive posture, avoiding direct eye contact with the HHH while searching his protective proximity, imitating his behaviour and acting as his extended arm. The HHH seemingly rewarded the son by allowing him to take over procedural tasks such as placing the crop cards and summarizing preliminary results. The son consequentially gained confidence, embodied in an upright torso posture, a stronger voice and intonation. Throughout the game, the wife pressed her lips together as if retaining or controlling herself. When prompted to speak the wife was fast and confident to respond, indicating attentiveness but also tension, possibly torn between the aim to be a strong negotiator and the objective to safeguard her reputation as a 'good (submissive) wife' (Apusigah, 2009; Kabeer, 1999). The wife did not compete for procedural tasks during the negotiation.

In line with power reports of the game participants, the speech sequence, speech shares, interruptions as well as the body language point to the HHH as being the most influential negotiator. However, comparing the HHHs suggestion with the household-level decision-outcome, the wife and the son had a substantial influence on the land allocation decision, too.

6.3.5. Power modes and trades (RQ6.3)

The interaction analysis of the negotiation did not provide evidence on direct trades, but on the three power modes: while the HHH and the son deployed power in their competition for procedural leadership, the HHH withheld power at content-level by inviting the son and the wife to express their interests. Depending on the context and decision domain, the son or the wife seemed to stay in the background, withholding power, too. While the wife abstained from the discussion about the HHH's maize field, the son explicitly reported to compromise his own interest in soybean cultivation to respect the interests of the HHH and the wife. Moreover, power was actively deployed for mutual support *e.g.* the wife supported the son's claim for individual land, the son suggested to grow vegetables for the wife and the HHH backed up the son's need for additional individual fields. Besides serving the promotion of individual interests, power was hence actively deployed as a social instrument, creating trust and bonds among household members. Despite the high level of cooperative behaviour, the negotiators were, at times, involuntarily overruled as expressed by speech interruptions, disagreements or the conscious disregard of new or opposing suggestions. It seemed as if the wife and the son competed for the position of the 'second most influential household member'.

6.3.6. Comparison to 'real-life negotiations' (RQ6.4)

Most (14/16) game participants described real-life negotiations to be literally 'the same' as in the game. One participant reported the HHH to be the sole decision maker in his household and another participant reported that there were no adult children so that the HHH and the wife were the sole decision makers. The reported power shares for the simulated and real-life negotiations (*cf.* Fig. 6.4) were similar, too.

6.3.7. Farm modelling results (RQ6.5)

We modelled the intermediary and final decision-outcomes in the whole-farm model FarmDESIGN. At household level, the model results revealed similar SOM balances and labour inputs, but significant differences in nutritional outcomes and profitability of the four land allocation decisions (*cf.* Fig. 6.7). While the suggestion of the male HHHs attained annual operating profits of about 2200 GHS/yr (USD 464), the wives' and sons' propositions attained more than double the profits, with about 5220 GHS/yr (USD 1160) and 6200 GHS/yr (USD 1302) respectively. The sons' and the wives' suggestions also had slightly lower SOM losses and labour requirements. The sons' suggestion was more profitable but also slightly more labour intensive than the wives' suggestion. When considering the profitability of the individual fields per scenario (*cf.* Fig. 6.7B), the profitability for the son was always the same (1176 GHC/yr) while the profitability for the wife was highest in the wives' own suggestion (772 GHC/yr), followed by the household decision, the HHHs'- (both: 497 GHS/yr) and the sons' suggestion (0 GHC/yr). When differentiating between male and female labour contributions (Fig. 6.7C), the wives' suggestion evinced the highest share of female labour on both, individual and household-fields, while all other scenarios entailed substantially lower female labour shares. Concerning the nutritional performance, the more diverse cropping pattern of the son and the wife translated into a greater nutritional diversity as compared to the HHHs' configuration (*cf.* Fig. 6.7D-F).

The sons' land allocation proposition performed best in terms of dietary energy and all nutritional values including micro-nutrients and vitamins. Compared to the household-level result, the sons' suggestion would deliver *i.a.* 2% more calories, 12% more proteins, 18% more fat, 18% more niacin and 41% more folate. The HHHs' and the wives' suggestion only provided about 70% of the calories of the household-level result and significantly less nutrients, micro-nutrients and vitamins. The wives' configuration provides more carbohydrates, fibre, calcium, sodium and vitamin C than the HHHs' suggestion, which in turn provided more proteins and fat, magnesium, niacin and vitamin A than the wives' configuration. The HHHs' suggestion provided significantly less vitamins than all other configurations, actually causing a deficit in vitamin C when comparing the (cooked) food supply with the household food needs, see Annex 6K.

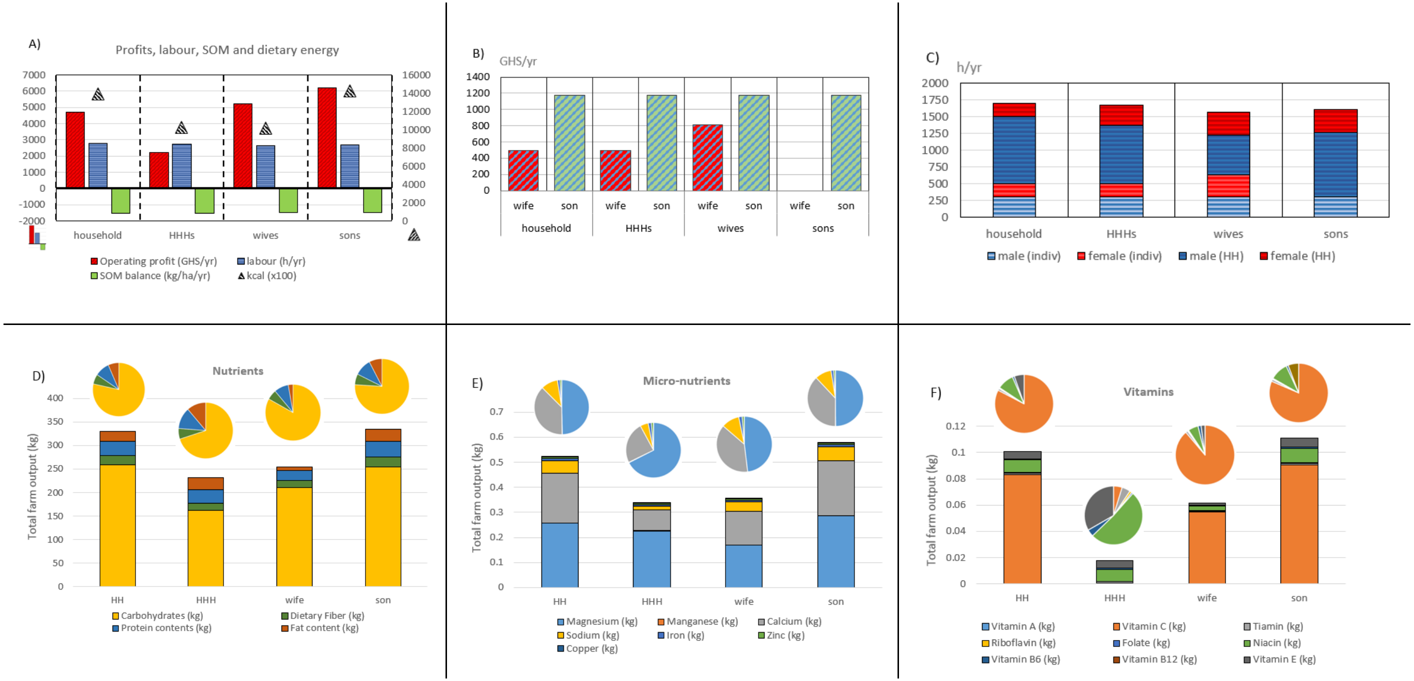


***Figure 6.7**. Performance of land allocation scenarios. Household-level performance in terms of A) profits, labour inputs, SOM and dietary energy, D) nutrients E) micro-nutrients and F) vitamins. Profitability in B) of crops on individual fields for the wife and the son respectively and in C) male and female crop labour inputs per scenario for individual (indiv) and household (HH) fields.*

It seems as if through the influence of the son and the wife the household-level decision-outcome became more diverse and much more profitable as compared to the HHHs suggestion.

6.4. Discussion

The serious game provided novel insights into land allocation processes within smallholder farm households in Northern Ghana: wives and sons envisioned a more diverse cropping pattern than the HHHs, significantly influencing the household-level decision-outcome despite their power shares being evaluated as relatively small (12-14%). The wives' suggestion was substantially more ambitious in terms of 'own profits' and female labour contributions as compared to the vision of the HHHs and the sons, possibly indicating a desire for additional responsibilities and liberties in agricultural tasks. While the HHH, as the land owner, held the strongest power position, he gave substantial room to the wife and the son to bring forward their individual interests, possibly due to a dependency on their labour and financial support, as typical for MRE households in Duko (Michalscheck et al., 2018a). Occasionally, the wife and son abstained from power, too, depending on process dynamics and decision domain. The choice or eventuation of power modes by an actor likely depended on his or her fall-back position (Agarwal, 1997; Apusigah, 2009; Doss, 2001; Padmanabhan, 2011), the prospective nature and amount of gains or losses (Ashraf, 2009; Iversen et al., 2006) as well as the prevailing divergence of interests among the negotiators. Power abstention according to decision domain has been described in previous studies (Anderson et al., 2017; Becker et al., 2006; Colfer et al., 2015; Jha, 2004). In line with observations by Agarwal (1997), household members were found to actively deploy power to support one another and to build coalitions. The strong mutual support among household members is consistent with the social security system in most of rural Africa, with people relying on each other's support, hoping for a return of favours when in need of help (Binswanger and Rosenzweig, 1986; Ligon et al., 2018; Ng'ang'a et al., 2016; van Rijn et al., 2012).

Despite the reported congruence between simulated and real-life negotiations, we think that the remarkably cooperative behaviour during the game might have been shaped by a desirability bias: the representative role, the audience and video recording possibly let the participants assume a more controlled, fair and formal behaviour than in real-life negotiations. Furthermore, despite observing a high level of mutual responsiveness and support among the negotiators, we did not discern direct trades during the negotiation. The final decision-outcome suggests, however, that each negotiator got his or her will on decision domains that were deemed personally important, which may be interpreted as indirect trade outcomes. The pathway of indirect instead of direct trades may express local norms of conflict resolution. The integrative negotiation style (Hames, 2012; Moran and Ritov, 2007; Walters et al., 1998), marked by a high level of cooperativeness, led to a win-win situation where each group over-estimated their own influence on decision-outcomes: on average, the HHHs assigned their spokesperson 80% of the power, the wives 20% and the sons 15%, which would add up to more than 100%, possibly explaining the high level of satisfaction with the household-level decision-outcome by all parties despite the multilateral compromises (Agarwal, 1997). The balance between joint and conflicting interests as well as intra-household dependencies may be described as a cooperative conflict (Sen, 1987).

We recommend adoption studies to explore patterns in power shares and power modes to better understand household-level decision dynamics and to inform debates on gender relations, particularly on women empowerment in agriculture (Alkire et al., 2013; Kabeer, 1999; Malapit and Quisumbing, 2015; O'Hara and Clement, 2018). Serious games should be played with additional household members to better represent the possible complexity including cooperation or conflicts between wives or sons. While we viewed household members to be the decisive executing agents in (land) resource allocation, we recommend putting household-decision-making into a larger context (Agarwal, 1997; Singh et al., 2016) by investigating how external factors, institutions (Abdulai, 1986; Lambrecht, 2016) and shocks, such as price fluctuations, credit constraints (Porgo et al., 2018), policy changes, extreme weather events (Tambo and Wünscher, 2017a) or personal losses (Valbuena et al., 2015), shape the individual interests and power positions and therewith household-level decision-outcomes. Furthermore, based on the described similarity between the game and real-life negotiations, HHHs do not hold the sole decision-making power but the contentual and procedural lead in land allocation decisions. Whenever decisions fall into the domain of a particular household member, we can imagine a funnel-like process with the key decision maker acting as a strategic gatekeeper at the funnel stem (*cf.* Fig. 6.8).

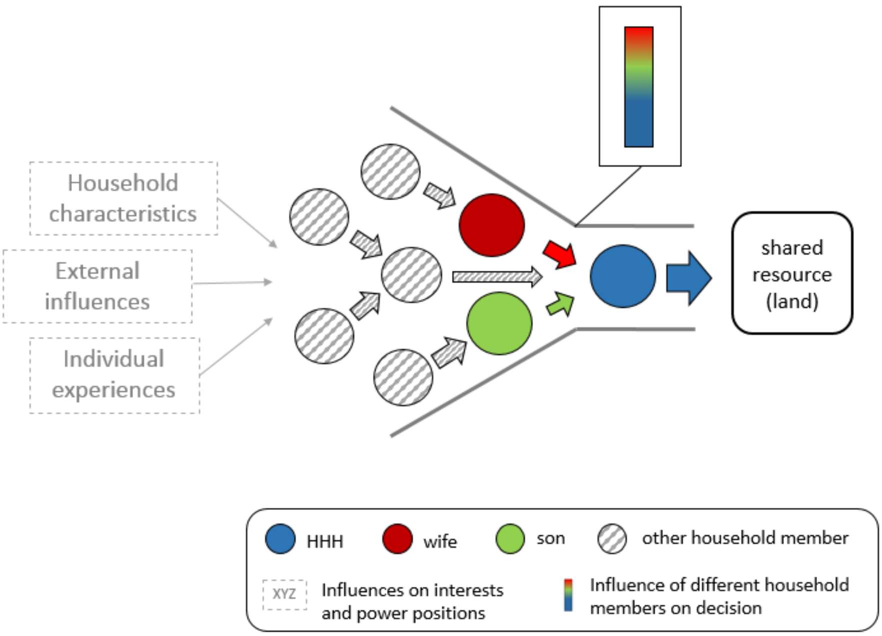


Figure 6.8. *Funnel model, conceptualizing how various household members influence the household head's decision over the jointly managed (land) resources. Depending on the decision domain, other household members may take up position at the funnel stem, holding the power of ultimate decision.*

The prevailing local gender norm 'the HHH decides' (Lambrecht, 2016) hence expresses HHHs being the 'central nodes' in intra-household land allocation decisions, holding formal decision-making power as opposed to the informal agency (Abdulai, 1986; Kabeer, 1999) of other household members, who nevertheless influence the HHH's decision. The importance of informal influence on natural resource management decisions was also reported by Elias (2015a, 2015b) and El Tayeb et al. (2003) and may be verified on a large scale by systematically reviewing data of ongoing research initiatives such as GENNOVATE (2018). Awareness on the systemic set-up of decision-structures, including who acts as the central node and who as peripheral nodes in relevant decision domains, may explain why certain changes or adoption decisions come about or not, bearing in mind that gender norms and relations and therewith power positions are in constant evolution (Doss and Morris, 2001; Elias, 2015a; Saito et al., 1994).

While, with our research, we aimed to play a careful observer's role, our findings are of high practical relevance for projects working with smallholder farmers.

- Firstly, the interplay and integration of various individual perspectives made the household-level decision on land allocation more profitable, agro-biologically and nutritionally more diverse and likely more resilient, seemingly setting the farm household on a better track towards sustainable intensification as compared to *e.g.* the individual land allocation suggestion of the HHH. Similar findings are reported in Elias (2015a), Jones et al. (2014), Lecoutere and Jassogne (2017) and Sumane et al. (2018). We hence think that project work and related research, including participatory modelling efforts, are likely to produce more sound and sustainable results when taking a gender transformative approach, engaging with different household members or stakeholders to each contribute their diverse perspectives.

- Secondly, we think that diversity is only likely to be expressed when participants feel safe. This is achieved when the game is realistic while being non-binding and explorative (Gugerell and Zuidema, 2017). We believe that a culturally-sensitive game design is a prerequisite for a sustainable cooperation with smallholder communities.

- Thirdly, we experienced our serious game as a cost- and time effective tool to explore intra-household dynamics and perspectives on local resource allocation. A serious game could be played to assess prevailing gender norms around particular resources or to obtain multilateral and interdependent feedback on a concrete suggestion for change. Interdependent feedback is the particular strength of games, going beyond the assessment of isolated opinions (Jean et al., 2018).

- Fourthly, a game or discussion is not just a learning opportunity for project researchers but first and foremost for participants. Games and discussions could, in fact, be primarily designed as learning events for the participants, promoting a local knowledge exchange before providing any external knowledge and viewpoints, strengthening the local self-determination potential of communities (Ryan and Deci, 2000; Stobbelaar et al., 2009). Games and discussions are opportunities for 'reframing' *i.e.* learning about the paradigms, problems and interests of 'the other' (Sterk et al., 2006). In terms of affordances, as described by Ditzler et al. (2018), we may describe games like ours as having a framing, visualization and integration role.

- Last but not least, new knowledge and skills are likely to impact the interests and power positions of household members (Agarwal, 1997; Doss, 2001). We recommend trainings to be as inclusive as possible, so that all household members have access to them, not missing out on information or skills needed to play an active and respected role in intra-household decision-making processes. Like Haider et al. (2018) and Johnson et al. (2015), we expect that wives and ‘the youth’ would disproportionately benefit from capacity building, eventually experiencing an empowerment in household-level decision-making.

We think that the real-life interplay of interests and power positions may look very different than in our game, depending on the prevailing negotiation culture (Agarwal, 1997) within a household, in a community or country. Our study, nevertheless, certainly provided rare insights into possible negotiation dynamics as well as novel insights into the prevalence and circumstances of different power modes shaping household-level decision-outcomes on land allocation.

6.5. Conclusion

Our serious game provided valuable new insights into negotiation processes around land allocation: the encountered integrative negotiation style led to the coalescence of the different intra-household perspectives into a household-level compromise rather than a unilateral decision-outcome. We observed a funnel-like process, where the HHH was the key decision maker acting as a strategic gatekeeper at the funnel stem but with the wife and the son having a significant influence on ‘his decision’. We find evidence and first explanations for the prevalence of different power modes *i.e.* for power being deployed, withheld or overruled. According to our whole-farm model results, the wife’s and the son’s influence led to a more sustainable and more intensive farm configuration as compared to the HHHs preference. We conclude that serious gaming has served well to uncover dynamics in farm land allocation decisions at household-level in Northern Ghana.

Discussion

7. General Discussion

This chapter briefly responds to each research question (7.1) and elaborates on the comprehensive insights of this thesis (7.2), including overall lessons learnt on intra-household decision-making dynamics and a matrix of local farm and farmer characteristics. I discuss the transferability (7.3) of my methods and findings as well as the contribution of this thesis to the debate on women empowerment in agriculture (7.4). I furthermore reflect on the interface between linear and complex systems thinking (7.5) before drawing brief and actionable conclusions for ongoing and future R4D projects aiming to support smallholder farmers (7.6).

7.1. Responses to research questions

In Northern Ghana, five project-proposed technology packages for sustainable intensification were evaluated as differently suitable for different farms and farmers, depending on their resource endowment, production orientation and the gendered access to resources (RQ1, RQ2). I found that male household heads (HHHs) held the bulk of the power, acting as gatekeepers of decisions on land allocation despite being heavily influenced by other household members due to mutual dependencies (RQ3, RQ4). Dependency, solidarity and individual interests shaped the negotiation, expressed through indirect trades and by power being exerted, withheld or overruled. While each thesis chapter provided a different but complementary viewpoint on inter- and intra-household diversity among local smallholder farm systems, additional insights are gained from considering these findings jointly.

7.2. Comprehensive insights

The chapters of this thesis strongly build upon one another: the knowledge gained on inter- and intra-household diversity (Chapters 2 and 3) was operationalized for a nuanced impact assessment of technology packages (Chapter 4). In turn, the identified intra-household differences in technology package evaluations inspired a deeper look into decision-making dynamics in order to better understand how individual interests interact and lead to farm-level decision-outcomes (Chapters 5 and 6). I extract overall lessons learnt on intra-household decision-making dynamics (7.2.1) and a matrix outlining farm- and farmer-type-specific characteristics, opportunities and constraints concerning agricultural production (7.2.2).

7.2.1. Decision-making dynamics

[Consensus]: *from Latin cōnsēnsus (agreement),*
*based on cōnsentiō (**feel together**).*

Through the study of intra-household decision-making dynamics, I identified gendered patterns in interests and power positions and learnt how the cultural norm 'the HHH decides' expresses the HHHs' formal agency rather than a unitary decision-making structure. Household members were remarkably congruent in their independent statements on intra-household power distribution, which encouraged me to think that even minor power shares were meaningful in time and across decision domains despite often being withheld or overruled. Based on my findings, I now imagine a funnel-like structure (*cf.* Chapter 6, Fig. 6.8), where various household members influence 'the gatekeeper' of a decision domain. In the negotiation process, I observed instances of conflict and cooperation, with household members making compromises while showing a high assertiveness on decisions of personal importance. I also observed that the smaller the power share of a household member the greater his or her flexibility *i.e.* the greater the acceptable compromise. In fact, despite partially compromising their objectives, most game participants (Chapter 6) and survey respondents (Chapter 5) reported to be highly satisfied with the overall decision-outcome (14/16 game participants > 80% satisfaction; 54/58 survey respondents > 90%). The high level of overall satisfaction seems to indicate that, for a bundle of interrelated decisions, unacceptable individual solutions (*e.g.* maize area too small) may become acceptable when compensated by other, highly satisfying solutions (*e.g.* ideal cowpea area). If this is the case, satisfaction might have to be measured at overall outcome-level rather than for individual decisions. I argue, that the analysis of individual decisions remains crucial for understanding negotiation dynamics (*e.g.* trades) and particular decision-outcomes. However, I may attenuate my statement on the unacceptability of whole-farm configurations on the basis of single unacceptable land allocation options (Chapter 5). Furthermore, while I have asked farmers about their minimum and maximum acceptable crop areas, I do not know about the extent of dissatisfaction associated to unacceptable solutions. I wonder whether there is a point along the range of unacceptable solutions beyond which the unacceptability is no longer compensable and at which an acquiescing attitude becomes untenable, possibly manifested through active resistance, *e.g.* in decision-implementation (Safilios-Rothschild, 1982; Sen, 1987). Concerning the compensability of decision-outcomes, one may ask in how far the 'domains of trade' have to be related in order to be compensatory? I hypothesize that the domains of trade may be completely unrelated but still relevant for as long as they constitute a conscious assertion or cut-back in interests affecting the overall perception of fairness (Brett and Thompson, 2016; Mislin et al., 2015). According to Antonides and Kroft (2005) as well as Carriero (2011), intra-household perceptions on fairness are likely to differ: the wives and the sons may feel treated well if their wishes are considered in 20% of cases, while the male HHH may expect to get his will in 80% of cases. While these numbers are just hypothetical, one may wonder what the prevailing patterns are in perceived fairness concerning household-level decisions. Beyond the actual decision-outcome, the form of communication likely shapes the individual perceptions of fairness, too (Bandura et al., 2011; Brett and Thompson, 2016). The different perceptions of fairness probably explain the above-mentioned relation between power shares and flexibility on decision-outcomes. In summary, if one knew more about the compensability of unsatisfactory decision-outcomes and the gendered perceptions of fairness concerning the overall participation in household-level decisions, I think one would be able to better evaluate the ‘social quality’ of whole-farm configurations.

For as much as I learnt about intra-household decision-making dynamics (Chapters 5 and 6), are there any additional insights that enrich my evaluation of the five project-proposed technology packages (Chapter 4)? In fact, rather than inferences about individual technology packages, the funnel-model may hold another explanation[4] as to why farmers generally adopt single components rather than entire technology packages: different package components are likely to fall into the decision domains of different household members *e.g.* the HHHs may be purchasing inputs, applying fertilizers and green manure while young men may be responsible for spraying and women for sowing, weeding and animal feeding. Full adoption of a package hence equates to a bundle of changes that affect various household members. Now, how likely is it that a particular bundle of ideal agronomic practices is automatically a balanced social suggestion, too? Knowing that farmers are likely to only adopt or adapt single or a subset of package components should hence be considered in the design and ex-ante testing of technology packages: each component needs to be beneficial and effective on its own. Cases, in which combined changes yield significantly greater benefits than single changes or in which single changes are not effective unless being part of a bundle of changes, have to be clearly communicated to farmers, so they may anticipate and weigh the individual and combined effects of partial adoption. The partial adoption also raises the question of how much of a difference an individual household member can make by merely adjusting technologies and techniques in his or her ‘own’ decision domains. I hypothesize that the potential impact per household member may differ considerably, depending on his or her actual interests and total influence across the relevant decision domains.

[4] Apart from the greater affordability of management (technique) as compared to technical (technology) components (Chapter 4).

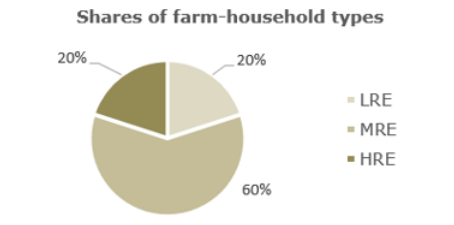
Despite the emergence of fascinating new research questions, the insights gained in the scope of this thesis already provide a much better understanding of how inter- and intra-household differences in Northern Ghana shape smallholder farm decisions. Furthermore, the information on inter- and intra-household differences in interests and power positions enrich the matrix of farm and farmer characteristics (Table 7.1).

7.2.2. Matrix of farm and farmer characteristics

Since the main research question concerns the impact of inter- and intra-household differences on farm decisions, Table 7.1 provides an overview that outlines these differences based on the insights gained throughout this thesis research. Horizontally, I distinguish between low, medium and high resource endowed (LRE, MRE and HRE) farm households and vertically between the male HHH, the wife or wives, the eldest son and daughter as well as the female HHH, with information about the latter being based on insights from Nyangua (Upper East Region) and Zanko (Upper West Region) as presented in Chapter 4. The matrix does not include the category of landless farmers (Chapter 3), due to insufficient information about their inter-and intra-household position and interactions.

The matrix is meant to support ongoing and future efforts in tailoring agricultural interventions to particular farm or farmer types *e.g.* women in LRE households or to 'the youth in agriculture' based on their interests, constraints and opportunities. While the matrix summarizes farm and farmer-type specific characteristics, it also accentuates the importance of the social context of targeted interventions *i.e.* whenever targeting a particular system component one needs to ask (the farmers) what are the benefits and disadvantages for other household or community members, fostering or hampering the envisioned positive effect of the intervention. Hence, beyond highlighting differences, the matrix illustrates the interconnectedness of system components since household-level outcomes are obviously shaped by individuals, while individuals are strongly grounded in household-level resource base, too.

Table 7.1. Matrix of farm and farmer characteristics



Farm / Farmer	Low Resource Endowed farm households	Medium Resource Endowed farm households	High Resource Endowed farm households	General farmer characteristics
	Relatively small households (labour constraint)[2,4]; little land; inputs too expensive (cost constraint); no private means of transportation[4]; techniques rather than technologies[3]; livestock: poultry[2,4] i.e. high dependence on crop-related soil fertility measures[4]; little post-harvest storage[2]; survival strategy[2]	Medium-sized household; not mechanized enough to 'step up' with household labour i.e. high hired labour shares; mixture of techniques and technologies; bicycles as main means of transport; livestock: poultry and small ruminants; relatively high legume ratio (labour intensive); income primarily from on-farm activities; most positive about technology packages: eager to learn	Large households (no labour constraint); off-farm income; technologies rather than techniques (services to community); large herd size: cattle as cash banks, providing manure for soil fertility; high shares of maize; motorbike and bicycles as means of transport (good access to input and ability to sell produce); post-harvest storage ability; large room to manoeuvre	
Male household head (HHH) [50-80% power; 96% satisfaction]	Food security central concern, hence HHH is fully in charge[5,6] (high power %).	"Development strategy"[2] requires (financial and labour) commitment of other household members[4,6], so the HHH is likely to share power.	Sufficient resources[2,4] to be relatively independent of support by other household members (labour may be hired): tendency for autocratic leadership style.	Gate keeper of many agricultural decision domains and central node of communication[6]. Responsible for food security[4,6]: emic justification for being the prime resource manager incl. land, homestead, livestock and means of transportation; highly cost and labour sensitive[4].
Wife/wives [10-20% power; 55% satisfaction]	Not enough household resources for wife to claim own land[2,4,6]; reducing food insecurity may free up room for participation in decision-making and for a more diverse cropping patterns[6].	Sufficient household resources for the wife to claim own land[2,4,6]; high instance of 'equal'- decision-making[6]; own production; own trade[4]; possibly educated enough for a non-agricultural job.	Wife can claim own land, but HHH not dependent on her support for his activities[1,2] (low fallback position); high market engagement[6]; might provide services to community (mill, well, shop)	Responsible for nutritional diversity[4,6], household tasks (strong labour constraint); possibly complex arrangements with competition and collaboration among several wives; wives and sons compete for influence[6]; market women (Duko)[6]; high curiosity towards new agricultural knowledge[4]; lower access to inputs, credit, technologies and information than men[4]; high information exchange among women (Duko, Nyangua)[4]; holds but often withholds power[5,6]
Eldest sons [10-20% power;75% satisfaction]	Important labour support or provider of remittances[6]. Typically low paid off-farm wage labour[2] and no or little room for growing own cash crops[3].	Most (likely) educated among all farm types[1,4]. Important labour support while on-farm, working hard on own cash crop fields[3],[4,6]; in case of successful schooling: urban non-agricultural job[2].	Either successful off-farm business-man or relatively HRE farmer with own lands provided by the HHH[2,4,6].	Important labour contribution; seeks opportunities: off-farm or cash crops on farm for education or marriage[4,6]; interested in technologies rather than techniques[4], but if the former is not affordable the latter is possible; Partly competes for decision-making power with the HHH[6], since the usually son stays part of the household and he will eventually take over from the HHH. Holds and tests power[6].
Eldest daughters [No information]	Labour support and leaving the household upon marriage[6].	Labour support and leaving the household upon marriage[6].	Labour support and leaving the household upon marriage[6].	Upon marriage will move into the household of the husband(s' family)[6], making her a temporary decision-maker in the parents' household.
Female HHH [No information]	Labour constrained and dependent on voluntary community support[4]. No or little direct access to inputs[4]. Vulnerable to further shocks.	MRE likely based on inherited resources, sustained by good family relations/support[4].	A HRE female HHH is probably engaged in trade rather than agricultural activities[4,6].	Power is likely shared between her and her adult children[4,5,6]; typically LRE or MRE[4]; limited access to inputs, low labour availability and dependent on male relatives for agricultural tasks such as ploughing[4].

[1](GARBES, 2014); [2]Chapter 2; [3]Chapter 3; [4]Chapter 4; [5]Chapter 5; [6]Chapter 6

It seems as if agricultural systems in Northern Ghana are not just cybernetic (Tittonell, 2013) but multi-cybernetic, fulfilling a multitude of partly shared and partly competing production objectives. Since many farms worldwide are run by families (Graeub et al., 2016), I expect strong and multilateral interdependencies between the social and ecological system components in many (smallholder) agricultural systems beyond the Ghanaian context, too (Berrouet et al., 2018; Bodin and Tengö, 2012). For R4D projects, insight into the vertical and horizontal diversity of farm systems hence provides a solid basis to formulate or adjust the theory of change (TOC) associated with proposed agricultural interventions (Mayne and Johnson, 2015; Rogers, 2014).

Based on the matrix, I would like to highlight two emerging issues, namely farm-type specific patterns of intra-household power distribution and the challenge of keeping youth in agriculture.

Patterns in intra-household power distribution

Concerning power distribution among farm and farmer types, I observed a shift in power structures with an increasing household resource endowment: LRE households are centrally concerned with food security. Food security is the responsibility of the male HHH, who therefore is unlikely to share his limited land and his power. In MRE households, there is a greater room to manoeuvre and the HHH depends on the commitment of other household members to work on his fields for a greater 'household' income. An MRE HHH is therefore more likely to provide own land to other household members and to grant them a share in decision-making. From this perspective, improving the food security situation of rural households in Northern Ghana is likely to have a positive effect on the empowerment of women and young men, who, in the households' process of stepping up, are granted land use rights and a greater voice in decision-making. However, the positive relation between an increasing household resource endowment and gender equality only seems to hold true until a certain wealth level. In HRE households the HHH is wealthy enough to mechanize and hire labour, rendering him less dependent on the support of other household members. The HRE HHH may still decide to generously allocate own land to his sons and wives, but the necessity for concerted decisions is certainly lower than for the resource constrained LRE and MRE types. To complement this observation, according to the farm typology for Northern Ghana by Signorelli (2016), gender equality was found to be lower in HRE as compared to MRE households. It seems as if male HRE HHHs are not only dominant within their households but also at community-level due to their economic power (hiring labour) and role as service providers (milling, shelling, ploughing, credits, motorized transport, resale of inputs). Although HRE households may be considered an interesting target group for change since they are financially able to test labour-saving technologies that are costly in their acquisition, there may be negative spillover effects at community level. For instance, labour-saving technologies decrease the intra-community employment opportunities, particularly for LRE households who will lose their seasonal job without being able to afford hiring the newly available labour-saving service themselves. Furthermore, from the technology evaluation in Duko (Chapter 4) I learnt that community relations may be marked by jealousy and competition, despite a strong intra-community support through saving groups and exchange labour. In line with Ratner et al. (2013) and Leach et al. (1999), I hence observe a situation of cooperative conflict at community level, too.

Keeping the youth in agriculture

Young men and women are the next generation of farmers, but for many of them agriculture does currently not provide a decent livelihood perspective. When asked to draw a vision of their future occupation, school children (N=350; 5-12 years old; Duko and Nyangua, *cf.* Fig. 7.1) drew themselves as policemen, nurses, teachers, but rarely as farmers, indicating that they dream of a better life than the tough and economically instable farm-based livelihoods of their parents. Students who do well in school tend to leave the community, looking for off-farm jobs in nearby urban centres or in the capital Accra (Bugri and Yeboah, 2017; FAO, 2012). The brain drain from rural communities feeds the urban narrative of farmers being 'behind' and of being 'societal losers'. Rural livelihoods need to offer a better perspective to the youth, but for as long as smallholder households struggle and face food insecurity, livelihoods are precarious and local and global out-migration will continue. Food insecurity in combination with armed conflicts has been a major driver of global refugee movements (Puma et al., 2018). The problem has reached global dimensions and global efforts are needed to understand and support local livelihoods. The FAO (2014b) identified six principle challenges for youth in agriculture, namely (1) insufficient access to knowledge, information and education, (2) limited access to land, (3) inadequate access to financial services, (4) difficulties accessing green jobs, (5) limited access to markets and (6) limited involvement in policy dialogue. While the subject of land access has directly been addressed in this thesis, all six challenges seem, to a greater or lesser extent, related to intra-household dynamics as well as the household-level resource endowment. For instance, daughters and sons of LRE households are likely to lack the financial means and the time to pursue higher education, since their remittances and labour contributions are direly needed by their families. The LRE youth furthermore has limited access to land and certainly no access to credit. They have no private means of transportation that would facilitate market purchases and sales and, for all of the above-mentioned reasons, they are unlikely to have a strong voice in local policy dialogues. In contrast, the HRE youth has access to education, credit, land and markets, constituting a good basis for participation in the local policy dialogue. Enabling a more equal access to higher education, agricultural credit and means of transportation may increase the voice of the LRE and MRE youth within their households and in the local policy dialogue, possibly leading to better perspectives concerning their agricultural livelihoods. I think that a matrix of farm and farmer characteristics is a good starting point for tailoring support measures to young farmers, since it defines and contextualizes their struggles and aspirations.

Figure 7.1. *Selected school children's drawings of their future professions: teacher, doctor, nurse, policeman, taxi driver.*

In conclusion, the joint consideration of all thesis chapters has provided great additional insight into local inter- and intra-household diversity as well as decision-making dynamics within smallholder farm households in Northern Ghana.

My research is locally anchored, so in how far can my findings be used for scaling?

7.3. Transferability

When assessing the transferability of the main thesis findings, one may question (7.3.1) the broader validity of the presented farm and farmer typologies (Chapters 2 - 4), (7.3.2) the potential for scaling of the five project-proposed technology packages (Chapter 4) and (7.3.3) the transferability of my insights into intra-household decision-making dynamics (Chapters 5 and 6).

7.3.1. Transferability: farm and farmer typologies

While the presented farm and farmer typologies were an attempt to 'scale down' the multi-dimensional smallholder complexity in Northern Ghana, one may ask in how far the horizontal and vertical diversity dimensions matter in other sites and contexts across the globe. Since the global farming systems literature emphasizes farm-household heterogeneity (Cortez-Arriola et al., 2015; Falconnier et al., 2015; Hammond et al., 2017; Tittonell et al., 2010) and gender studies emphasize intra-household differences (Anderson et al., 2017; Colfer et al., 2015; Ngigi et al., 2017), the question does not seem to be WHETHER farm systems are sufficiently diverse for a meaningful categorization, but the point to be made is that both diversity dimensions should be considered jointly. Both, inter- and intra-household differences seem to prevail and shape decision-outcomes in most smallholder family farms. Where farms are run more as a business with employees rather than family members, typologies may still be instructive to understand inter- and intra-enterprise differences. Despite defined decision domains (through job descriptions) and formal power distribution (hierarchies), personal interests and actual power may deviate from the formal agreement (Cobb, 1980; Hirigoyen and Villeger, 2017; Hoffmann, 2002). Deviations between de jure and de facto decision domains may be based on the actual or evolving needs of the company, the actual skillset of the employee as well as collegial agreements or rivalry (Bedarkar and Pandita, 2014; Cai et al., 2018). While business culture is an important determinant of power distribution and roles, societal gender norms often shape the latter, too (Bajdo and Dickson, 2001; Stamarski and Son Hing, 2015). The conceptualization of farm and farmer diversity provided in this thesis hence seems to be relevant for many types of farm systems, ranging from small family farms to larger agricultural enterprises worldwide. The typology results will differ depending on the research question and stratification criteria. The suitability of statistical or participatory approaches for typology construction depends on the number of relevant farm units and on the possibility to safely engage farmers or farm employees into qualitative interviews and group discussions. In conclusion, there seem to be many opportunities to use this thesis research as an example for a joint and systematic assessment of horizontal and vertical diversity, integrating or complementing existing farm systems knowledge.

7.3.2. Scaling of project-proposed technology packages

Scaling of a particular technology or technique refers to the increase (*e.g.* number) or expansion (geographically) of its use (Frake and Messina, 2018; Millar and Connell, 2010). According to Wigboldus et al. (2016), scaling may be promoted by a push-approach (promoting the value of specific changes) or a pull-approach (changing enabling conditions). The idea of promoting a particular technology package among particular farms and farmers corresponds to a push approach. Examples for the pull approach are to improve the availability and affordability of agricultural credits, of ploughing services and agricultural machinery such as shellers, of post-harvest storage facilities or of private means of transportation such as bicycles. At first glance, these changes in enabling conditions seem meaningful given that food security, cost of and access to technologies as well as labour constraints seem to be the major development obstacles for LRE and MRE households. Responsible scaling, however, requires further contextual insights. According to Stilgoe et al. (2013) scaling is considered to be responsible if it is anticipatory ('what if it goes to scale?', trends), responsive (to societal needs and concerns), reflective (repetitive evaluation of functionality according to defined purpose) and inclusive (in scope, process, efforts and in terms of beneficiaries). Wigboldus et al. (2016) propose the PROMIS (Practice-

Oriented Multi-level perspective on Innovation and Scaling) framework, which combines a multi-level perspective (MLP) on socio-technical transitions (Geels, 2002) with the theory of modal aspects (Basden, 2015; Jahanyan et al., 2012), allowing a heuristic exploration of relevant dimensions and dynamics involved in innovation and scaling. While a responsible scaling assessment for the five project-proposed technology packages is beyond the scope of this discussion, I believe the findings of this thesis provide a solid fundament for a systematic assessment of responsible scaling opportunities and of possible implications.

7.3.3. Transferability: decision-making dynamics

While this thesis focused on intra-household dynamics, the applied methods and analytical approaches seem to be relevant for explorations of decision-outcomes in any other multi-stakeholder context with shared resources, too. The concepts used in this thesis seem to be transferable since decisions will equally be shaped by different interests and power positions, with dynamics marked by trades as well as power modes. Moreover, the methods I used seem to be transferable, too, and I proofed that abstract concepts, like power and satisfaction, can be communicated and assessed through simple comparisons and visualization tools such as the stick-score method. Serious gaming furthermore turned out to be a simple, cost and time-effective method to capture household-level negotiation dynamics. However, the transfer to different cultures, demographics and institutional contexts will require adjustments in the research design and data analysis. Adjustments are, for instance, already necessary when shifting from one community to another within Northern Ghana: working in Duko, a Dagomba farm community with only one female headed household, meant that in my research I set an exclusive focus on dynamics in male headed households. In Nyangua, female headed households are much more common, so that male and female headed households need to be sampled and a distinction between them may be made during the data analysis. In Ghana, there are more than 110 ethnic tribes, many with different languages and cultural norms (Cefan, 2018), spanning across seven agro-ecological zones (Germer and

Sauerborn, 2005), implying the necessity of variations in research design. The research underlying this thesis has clearly traded quality for quantity *i.e.* given the limited time available for data collection I have prioritized depth and context over a greater sample size. 'Small but thorough' has been the right approach in order to develop first mental models of how decision-outcomes in local smallholder households come about (Chapter 5) and in order to gain a refined understanding of possible negotiation dynamics (Chapter 6). Nevertheless, to compare and contextualize my findings, quantity does matter, hence more data is needed on intra-household differences and decision-making dynamics in different communities, different regions and different countries. Furthermore, a larger data-set would allow building a typology of intra-household power structures, which could support development projects understanding local decision-making dynamics leading to or hindering adoption decisions. One needs to keep in mind that, most likely, within individual households there are different power structures for different decision domains. The assessment of interests and power positions should therefore be domain specific. For the key agricultural domains (crop and livestock types, agricultural tasks, technologies and techniques) R4D projects may systematically inventorize knowledge on intra-household or intra-community interests and power positions. The inventory could then be complemented by practices for sustainable intensification, as listed by Pretty et al. (2018).

7.4. Empowerment Debate

Based on the gained insights into decision-making dynamics, I wonder whether change-fostering-projects should focus primarily on the gatekeepers of the respective decision domain in order to be most effective (*cf.* funnel model)? It seems as if projects in the past have done precisely that by focusing much of their survey work, trainings and discussions on powerful male household heads. Meanwhile, evidence has grown on the positive household-level effect of providing training, resources and opportunities to women. For instance, concerning farm land allocation it has been established that better land rights for women improve their bargaining power and decision-making over consumption decisions (Grabe et al., 2015; Santos et al., 2014). Other studies found that increased income to women led to an enhanced agricultural productivity and food security through better feeding and care practices (Duflo, 2003; Kennedy and Peters, 1992; Malapit et al., 2015). In line with these findings, since the 1990s, women empowerment has been a key concept and major goal in development discourse (O'Hara and Clement, 2018). Its importance was institutionalized at high level with the establishment of UN Women, the United Nations Entity for Gender Equality and the Empowerment of Women, in 2010. The United Nations' Sustainable Development Goal 5 confirmed the importance, setting targets to achieve gender equality and to empower all women and girls (UN, 2015). Beside these high-level targets, many grassroots projects on women empowerment have emerged. One example is the Global Fund for Women, declaring women as the most suitable agents for change (GFFW, 2018). By providing trainings for women in agriculture, the fund reported to have achieved a 5-50% increase in crop yields and a 30% increase in women's income among participants. Furthermore 25% of the women added one or more income-generating activities, women reported to enjoy more respect, that they became decision makers in their homes and taking leadership roles in the community, joining village councils and forming advocacies.

While women empowerment has received considerable attention by Research for Development projects and institutions, measuring empowerment and tracking respective progress constitutes an ongoing challenge. In 2012, the Oxford Poverty & Human Development Initiative (OPHI), USAID and IFPRI jointly launched the Women's Empowerment in Agriculture Index (WEAI)(OPHI, 2014). The WEAI captures and compares within-household differences in opportunities in various aspects of rural agricultural livelihoods, including input to and autonomy on agricultural production decisions, access to and decision-making power about productive resources, control of income use, community leadership and time allocation (Alkire et al., 2013). Essentially, the WEAI is about 'the voice' of different household members in agricultural decisions, so how does it relate to the concepts and the focus of this thesis?

While the WEAI measures 'empowerment' in a number of agricultural domains, thesis Chapters 5 and 6 zoom in on the single aspect of land allocation, measuring gendered power shares. The WEAI is not concerned about land allocation in particular, but about land ownership as well as the amount of input to decisions on food and cash crop farming. For the WEAI, the 'amount of input' to a decision is derived from the number of decisions (*i.e.* none, few, some, most) a person contributed to, while in this thesis a person's influence is measured in terms of effective directional contributions to individual decisions. While, according to the WEAI, all household members may be equally empowered, the concept of power shares used in this thesis implies that household members are competing for influence on shared resources. This conceptual disparity is reconcilable by scaled thinking: while household members may compete for single decision-outcomes (micro-level), the feeling of fairness and 'voice' seems to be based on a multitude of rather than single decision-outcomes (macro-level) as discussed in Section 7.2.1. While the WEAI-survey data would perfectly contextualize my own work, the in-depth insights on intra-household dynamics gained through this thesis research would have never emerged from it. Furthermore, it is important to remember that any normative empowerment indicator, such as the WEAI, rather reflects the values of those who are measuring than of those whose empowerment is assessed (Kabeer, 1999).

Despite the different emphases, the WEAI and the approach of this thesis have a very important aspect in common, which is the holistic social systems perspective, considering the characteristics and interests of men AND women. Linking back to the question of 'whom to target in the decision funnel in order to achieve change?', I would like to raise two cohesive concerns: first, seeking change through targeting women in male dominated domains can be considered an expression of working with complex rather than linear systems, provided that one is not only talking about a shift in focus from men only to women only. Focusing on and promoting change on single (social or bio-physical) elements of a complex system is likely to have unforeseen consequences. Second, taking a more systemic view will reduce but not rule out unforeseen consequences, so that any externally identified solution can only be a careful suggestion for change. Based on our finding on the potential unacceptability of most model-proposed land allocation options (Chapter 5), we, researchers and development agents, need to consider that non-adoption might be the best choice for a farmer, given his or her interests, priorities and understanding of whole-systems consequences. For situations where non-adoption is not 'the best choice' but owed to limitations such as the non-availability or accessibility of inputs or tools, a lack in knowledge and skills or institutional constraints, there seems to be a true demand for external mediation through institutions ranging from local NGOs and businesses to the national government and international development agencies. In line with Francis Bacon's statement 'knowledge is power' (1597), I believe that ensuring truly equal opportunities, *e.g.* equal access to trainings for all household members, has the potential to bring about important change. External knowledge, trainings and new opportunities hence should be offered in ways that effectively reach as many stakeholders as possible so that they themselves may decide what they are interested in, whether or not, when and how they would like to apply their new knowledge or to seize an opportunity.

So how to distinguish whether low technology adoption is a sensible farmer's choice or a call for support? I think that, as far as possible, development projects should not base interventions on assumptions or calculations only, but they should ask and listen carefully (Sirolli, 2012) to as many stakeholders as possible. Good communication is fundamental for sustainable development projects or businesses, especially if the change we talk about is not about our own lives and not in our own hands in the first place (Berg and de Jong, 2002). It is not just a question of efficiency but a question of basic respect. My theory of change is that humbly offering cooperation with full commitment and curiosity will foster change and contribute to pathways of sustainable development for smallholder farm systems. These reflections are in line with calls for an

African green evolution rather than a revolution, increasing the resource use efficiency and strengthening (empowering) local farm systems building primarily on local farmers' knowledge, interests and capacities (Tittonell, 2008). I suspect that any remaining imperial claims of (external experts) 'simply knowing better' (than farmers themselves) are related to the scientific desire to 'calculate and understand it all'. In this context, I would like to share my reflections on agricultural research at the interface between linear and complex systems thinking.

7.5. Linear versus complex thinking

'All models are wrong, but some are useful' (Box and Draper, 1987)

Currently, a large part of agricultural systems research employs an interdisciplinary approach under a linear systems model, assuming that the more is known about system features the better a systems' set-up and behaviour may be explained and predicted (Ali et al., 2016; Amare et al., 2018; Douxchamps et al., 2015b; Duflo and Udry, 2004; Jones et al., 2017; Kazianga and Wahhaj, 2017; Lalani et al., 2016; Tambo and Wünscher, 2017b; Thomas et al., 2018). In this thesis, the linear approach is expressed in the use of a data-intensive whole-farm model (Chapter 4) and the attempts in predicting decision-outcomes by combining independent reports on interests and power positions (Chapter 5). The Newtonian model carries the linear-mechanistic view to extremes by assuming that the interaction of interests and power positions may be understood through a simple vector calculation. The Newtonian model was an attempt to break down a complex situation into its very basic components, despite knowing that the underlying data only allowed a snapshot in time, illuminating only a few out of many aspects. In fact, agricultural systems are described as complex adaptive rather than linear systems (Hall and Clark, 2010; Upton, 1987; van Mil et al., 2014; Wigboldus et al., 2016) with many interdependencies between system components and with causes and effects that may be disproportional and distant in space and time. The transition from linear to complex shines through in my analysis of decision-making dynamics, *e.g.* in my hypothesis that even if power is withheld, it is meaningful in time and across decision domains. Furthermore, the complexity of farm systems is expressed in my model-based explorations, for which I used an evolutionary algorithm that does not predict a certain farm configuration but that generates a 'cloud of possible futures'. These possible futures may then be discussed with farmers, whether by discussing concrete alternative farm configurations (cloud points) or emerging patterns (cloud shapes and trends) such as trade-offs associated to the increase or decrease in crop areas or animal numbers. While we might (currently) not be able to predict a complex systems' behaviour, we are able to identify system elements (farm resources, interests, power positions) and patterns (farm and farmer types, modes of interaction) that allow us (researchers and development agents) to build useful mental models of possible dynamics (Ali et al., 2016; Duflo and Udry, 2004; Hunecke et al., 2017; Jones et al., 2017; Tambo and Wünscher, 2017b). Another example for development research operating at the interface between linear and complex relations are Randomized Controlled Trials (RCTs) and Agent Based Modelling (ABM). RCTs test the effectiveness of different development interventions by comparing groups that did or did not receive a treatment (Alwang et al., 2017; Duflo et al., 2007; Kamali et al., 2002; Karlan et al., 2017). The approach acknowledges that living systems are complex and that changes ensuing a treatment might derive from other causes. These causes, however, are assumed to equally affect the control group and may therefore be factored out, allowing to establish a causal link between a treatment and its outcomes. ABMs simulate actions and interactions of autonomous agents *i.e.* individuals or collective entities in order to assess system-level effects (Helbing and Balietti, 2012; Kremmydas et al., 2018). Hence rather than deriving simple patterns from complex contexts, ABMs use information on 'simple patterns' to model and analyse possible complex outcomes. Similar to the explorations in the whole-farm model FarmDESIGN, ABMs do not claim to predict outcomes, but to explore possible futures. So, is it all about asking the right questions and choosing the right level of detail to identify meaningful patterns even in complex adaptive systems? As part of scientific meticulousness, we (researchers) often try to understand as many details as possible on individual (farm) system components, while this might be counter-productive as soon as the rough whole-systems perspective and the interdependencies among the components are lost out of sight. There seems to be an important difference between trying to understand a systems' functions by its parts (ABM, Newtonian-model) versus by deriving patterns from complexity (typology, elements of decision-making). In the three-step R4D model (*cf.* General Introduction, Fig. 1.3), the difficulty in identifying the 'right problems' and 'the right solutions' may be associated to the balancing act between linearity and complexity: if simple patterns (linear problem statements) are derived from a complex reality and if these simple patterns are then used to design simple solutions for complex systems, the solutions are probably too simplistic, entailing unforeseen consequences that curtail adoption. So, how do we know that we found the right level of detail and meaningful simplifications of complex systems? It seems to be all about developing solutions in sufficient interaction and consideration of the complex reality for which they are intended. This thesis has provided a glimpse into inter- and intra-household diversity and possible dynamics which shall make us, researchers and development agents, cautious and humble when proposing simple (technical) solutions. While one can never be sure to propose a comprehensively good solution, participatory research and co-design cycles (Botha et al., 2017; Dogliotti et al., 2014; Gray et al., 2017; Martin et al., 2011; Schindler et al., 2016) are certainly ways of reducing the unforeseen consequences and of getting feedback from the actual owners of change, namely the people who take decisions on the use of their resources. With my thesis research, I did not aim to change farmers' but rather researchers' attitudes and decisions: by demonstrating the added value of conducting interdisciplinary research, partly based on linear partly on complex thinking, I hope to encourage fellow researchers as well as development agents to also take an in-depth and systematic look at the complex social dimension when proposing any (technical) change for smallholder farm systems.

7.6. Synthesis and conclusions

In synthesis, I would like to highlight the following key messages that have emerged from this thesis:

- To effectively support local smallholder farmers, R4D projects are well advised to assess possibly competing interests around any proposed change.

- Farm and farmer diversity should be explored systematically and jointly.

- Pathways for sustainable intensification are made up of sequential decisions for change, spanning over different decision domains that are administered by different household or community members. Consciously embarking on a pathway for sustainable intensification hence requires the concerted action of various stakeholders that are empowered to do so.

- Non-adoption of an innovation might be the best choice for a farmer, given his or her interests, priorities and understanding of whole-systems consequences.

- While household members may compete for single decision-outcomes (micro-level), the feeling of fairness and 'voice' seems to be based on a multitude of rather than single decision-outcomes (macro-level).

- Improving the food security situation of rural households in Northern Ghana is likely to have a positive effect on the empowerment of women and young men.

- Smallholder farm systems are complex, but patterns and correlations are meaningful in the context of a whole-systems perspective.

- A systematic overview of local farm and farmer characteristics as well as participatory inquiries help to understand possible decision-making dynamics, providing a solid basis to formulate or adjust an interventions' theory of change as well as a theory of scaling.

I conclude by expressing my hope that this thesis may contribute to a responsible scaling of agricultural interventions, since it will be the interactive sum of successful local changes that will add up to the global change that is required to sustainably feed the world.

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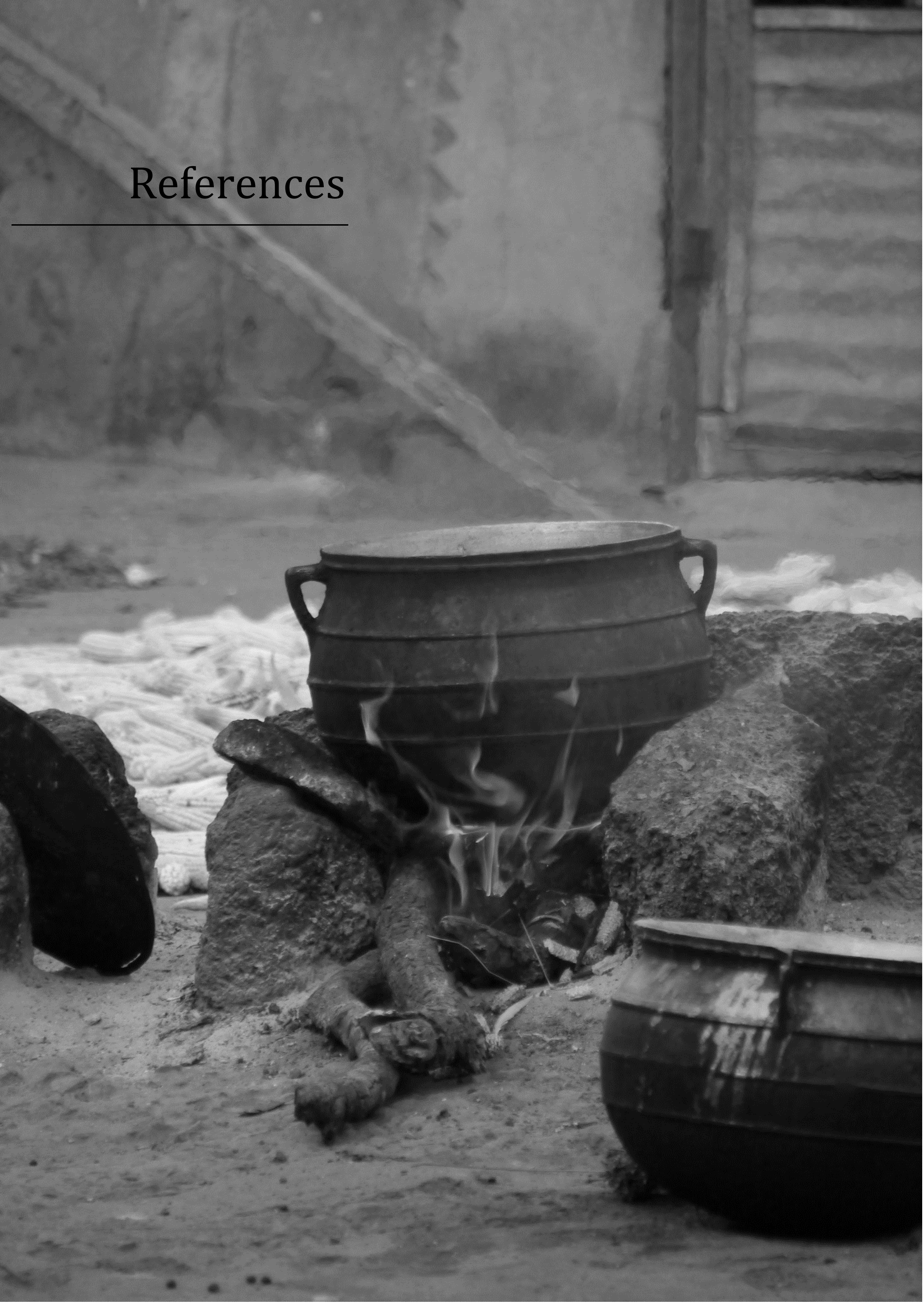

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Annexes

Annex 1A

The Ghana Africa RISING Baseline Evaluation Survey (GARBES, 2014) data (N=1284) indirectly confirmed the relevance of project-proposed technologies: respondents that knew about Africa RISING but did not participate in project activities (n=233) were asked about their reason for non-participation. None of the respondents indicated that the proposed technologies were inappropriate or too expensive and only one respondent mentioned that the activities were irrelevant or too risky, respectively. Instead, some respondents stated that they had no time to participate (15%) or that their attempt to participate was 'turned down' by the project (12%). Most (57%) respondents indicated that they did not have enough information to decide for a participation. The project, *i.e.* their trials on the selected technologies and techniques, hence seemed to be attractive to farmers, provided that they had enough information.

Annex 1B

Along the lines of the three-step R4D-process (*cf.* Fig. 1.3), I conducted a short survey in Duko (NR) and Nyangua (UER), asking farmers (N=89, age: 24-60 years, mean: 44 years) what, for them, were the most pressing problems (0=no, 1=low, 2=medium, 3=high importance (I)) in agricultural production, whether they were aware of any solutions and whether or not Africa RISING was supporting them with these solutions. I also asked whether farmers were implementing the solutions and if not, why.

The results (Table A1.1) revealed that, in terms of problems, farmers assigned the highest importance to the high cost of fertilizer (I=2.38), the lack of access to credit (I=2.38) and the low soil fertility (I=2.37).

Table A.1.1. *Problems, awareness on solutions, perceived project support, reported adoption and reasons for non-adoption by farmers in Duko (NR) and Nyangua (UER) respectively.*

Community: DUKO (n=26)				
Problems of highest (importance)	**Aware of solution? (n=26)**	**Supported by AR?**	**Adopted?**	**Reasons for non-adoption**
high cost of fertilizer (3.00)	100%	77%	96%	unavailability of fertilizer subsidy
lack of access to credit (2.96)	100%	8%	87%	high interest rates for available credits
low yields (2.96)	100%	95%	100%	-
high post–harvest losses (2.96)	93%	100%	79%	lack of post-harvest equipment/ costly measures
low soil fertility (2.96)	100%	100%	100%	-
high costs of seeds (2.92)	100%	96%	96%	-
lack of processing equipment (2.85)	92%	42%	43%	costly equipment, no subsidy available for processing equipment, HRE: too small for large acreages of production
Community: NYANGUA (n=63)				
high costs of pesticides (2.27)	95%	38%	100%	-
fluctuations in market prices (2.19)	18%	13%	88%	-
lack of access to credit (2.14)	87%	38%	96%	repayment issues with credit hinder the farmer to take out a (new?) loan
high cost of fertilizer (2.13)	100%	27%	100%	-
low soil fertility (2.13)	100%	22%	100%	-

- not applicable or no pattern identified

The vast majority (95%) of the respondents indicated to be aware of a solution to problems of medium or high importance. 44% of the respondents indicated that Africa RISING was supporting them with these solutions and 95% of the respondents reported to adopt the solution that they described. It seems as if the narrative of a low adoption rate is an external perspective rather than the farmers' point of view.

Responses however differed in the two communities, with farmers in Duko reporting a relatively high project support, except for the access to credits and the lack of processing equipment. Respondents in Duko furthermore indicated a low adoption rate of post-harvest technologies. Reported factors hindering adoption in Duko were the high costs and unavailability of inputs. In Nyangua, on average, problems were perceived to be of lower importance than in Duko, with higher adoption rates of solutions but a much lower perceived project support. The lower project support in Nyangua might be owed to the community's remoteness as compared to Duko and its' proximity to the main IITA office in Tamale, which leads the Africa RISING activities.

Within the communities, we furthermore identified differences in problem importance and perceived project support according to resource endowment (RE) and sex.

In Duko, respondents associated to medium and high RE households assigned a greater importance to low yields and the unavailability of inputs such as good quality seeds, fertilizers as well as livestock feed (fodder). Possibly, MRE and HRE respondents feel that they could seize more opportunities if inputs were available, while for LRE respondents the affordability would be of primary concern. Concerning gender differences in Duko, unavailability of pesticides and fertilizers as well as low crop yields were of greater concern to male respondents, while inequity within households was of greater concern to female respondents. On four problems (pesticides unavailable, lack of processing equipment, livestock pests and diseases and high cost of fertilizer) men felt less supported by Africa RISING than women. We hypothesize that the small-scale project-support made a larger difference to women than to men and, concerning processing equipment, that men and women might have been thinking of different tools and machinery (shellers, mills) depending on gendered processing tasks.

In Nyangua, high cost of seeds and damage through wildlife were of highest concern to LRE respondents, tractors services of highest concern to MRE respondents and processing equipment of highest importance to HRE respondents among the types. Similar to the situation in Duko, male respondents felt significantly less supported by Africa RISING than female respondents on the following three problems: on solutions to fluctuation in market prices (male: 0%, female: 25%), to fodder unavailability (male: 2.5% and female: 27%) and to the unavailability of fertilizers (male:2.5% and female 26%).

Annex 2

Table A.2. *Mean ±SEM of clusters (farm types) on all variables.*

Variable	Farm Type					
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Share of sample (%)	11%	10%	13%	46%	14%	6%
Household						
Age of household head (Years)	57.5±4.92	45.4±4.37	49.5±4.63	44.5±2.32	50.9±4.17	50.5±6.95
Size of household (No.)*	26.4±2.06	17.3±1.80	16.1±2.30	11.2±1.13	18.3±2.84	10.8±2.75
Land Use						
Cropped land area (ha)*	3.6±0.85	6.3±0.81	5.2±0.62	3.5±0.30	2.5±0.33	2.6±0.51
Maize ratio*	0.54±0.08	0.39±0.03	0.38±0.03	0.41±0.02	0.74±0.05	0.47±0.09
Other cereal ratio	0.10±0.05	0.23±0.07	0.07±0.03	0.13±0.02	0.12±0.06	0.21±0.09
Legume ratio*	0.15±0.07	0.31±0.10	0.32±0.05	0.30±0.03	0.04±0.02	0.12±0.12
Tuber ratio	0.19±0.05	0.04±0.02	0.14±0.03	0.09±0.02	0.09±0.04	0.04±0.04
Livestock						
Herd size (TLU)*	9.3±1.36	6.0±1.60	2.4±0.31	1.9±0.22	2.3±0.51	0.3±0.08
Cattle ratio	0.77±0.02	0.74±0.08	0.07±0.07	0.12±0.05	0.09±0.06	0.0±0.00
Small ruminant ratio*	0.19±0.02	0.19±0.07	0.79±0.07	0.70±0.04	0.67±0.06	0.11±0.11
Poultry ratio*	0.04±0.01	0.07±0.01	0.14±0.04	0.18±0.02	0.24±0.06	0.89±0.11

Labour						
Total labour (hours year^{-1})*	2403±274	3320±425	4994±378	1906±158	1847±410	1168±315
Hired labour ratio*	0.04±0.02	0.03±0.02	0.08±0.03	0.14±0.02	0.07±0.02	0.07±0.04
Female labour ratio	0.11±0.02	0.15±0.03	0.14±0.05	0.13±0.02	0.24±0.04	0.22±0.11
Food Security						
Food self-sufficiency (months year^{-1})	8.1±0.74	9.0±1.09	8.2±0.80	5.7±0.50	6.2±1.06	4.8±1.49
Income						
Off/non-farm income (%)*	32±8.18	9±4.42	16±3.51	14±2.56	8±1.70	25±10.41
Crop sales (%)*	15±0.05	55±0.03	30±0.10	45±0.04	23±0.04	26±0.09
Livestock sales (%)*	9±0.03	19±0.08	27±0.04	20±0.02	22±0.08	42±0.06

Asterisks (*) indicate variables used for construction of the typology.

Annex 3

Description of farm types as defined in the participatory typology

Type A. Pukparkara ('Big farmers, men'): HRE, market-orientation

Constituting the smallest class in each community with the exception of Tingoli, where only the landless were fewer in number, farmers of this category cultivated the largest land areas of at least 4ha. In Kpalung up to 32 ha were reported to be farmed. Only 8% of survey respondents were classified as belonging to this group. Commonly headed by more mature household heads of approximately 40-60 years of age, households associated with Type A were characterized by large, polygamous families, swelled by the ranks of extended family members attracted by the relative wealth of their patron. However, younger household heads with smaller families, who had inherited ample land and resources form their late fathers, were also represented in this category. Among 'Big Farmers' the key objective of farming was production for market. Generally, the sale of cash crops as a primary livelihood strategy translated into allocation of the majority of land to the cash crops of the season: mainly soybeans (*Glycine max*) (Fig. A3-B), rice (*Oryza sativa*) and sometimes tobacco (*Nicotiana tabacum*) as a lucrative end-of-season crop, and reservation of a smaller portion to food crops: mainly maize (*Zea mays*) - used to prepare the staple dish called *sagim* or *tuo zafi,* and yam (*Dioscorea*) used to prepare another common dish- *fufu* (Fig. A3-A). Despite their commercial orientation, farmers typically aimed at producing enough maize grain to supply their households with food for the entire year to ensure self-sufficiency, and only considered selling surplus grain (Fig. A3-L). Maize yields were generally favourable as farmers could afford to timeously apply the recommended rates of fertilizer. Since these farmers were not in a hurry to buy food in the lean season, they were also not in a hurry to sell their crops, and could thus afford to wait until market prices were high. In the meantime, grain was stored in large traditional huts called *kambong* (Fig. A3-C) or in market-ready bags.

Because 'Big farmers' could afford to send their children to school, the pool of family labour was constrained, and thus outside labour was hired in for weeding and harvesting of labour-intensive cash crops. Up to 30 migrants or 'Small farmers' (Type C) might be hired per season. An exchange labour-system based on friendship, marriage ties and traditional youth work groups was also readily exploited. Income generated from crop sales allowed farmers to keep large animal herds. Most of the cattle in the communities were owned by members of this category; up to 100 head. Herds were tended by Fulani herdsmen, who were reimbursed in kind for their services, or by village children who constituted family- or exchange labour. Manure from the cattle was sometimes applied to fields as an organic soil amendment. In terms of small ruminant ownership, sheep were preferred due to their higher market price. Fowls were kept around the household compound, and slaughtered for sacrifices, funerals and honouring of guests. Livestock sales were minimized as a source of income, and limited to the sale of old or sick animals. Cash generated from crop sales was used to replace slaughtered or sold animals, and farmers aimed to invest in more cattle to expand their herds. During the off-season many 'Big farmers' turned to business ventures such as food-stuff trading; collecting produce from other farmers and selling this as a source of income. Other off/non-farm activities included hiring out tractor services (Fig. A3-E) and participation in the transportation industry as drivers of 'motorkings' (motorbikes equipped with a broad cargo trailer) for example.

Type B. Pukparsagsa ('Medium farmers, men'): MRE, variable orientation

In all three communities, 'Medium farmers' comprised the second largest category. More than half of all the survey respondents were classified as belonging to this group. Farm sizes ranged from 0.8 to 4 ha, with the largest cultivated areas belonging to farmers in Kpalung community. Despite encompassing households varying in size from 6 to 30 individuals, and household heads of different ages, it was generally agreed that most 'Medium farmers' were young men of 25-35 years. These farmers had few dependents and many still lived under the care of their father, who, as senior household head, bore the burden of feeding his extended household. The rest of the category comprised more mature household heads between the ages of 35 and 40, with multiple wives and associated larger families.

Due to the diverse household composition among 'Medium farmers', there were also noticeable differences among production objectives. Nevertheless, it was agreed that most farmers produced food- and cash crops for both household consumption and market. Many younger farmers with smaller families pursued a strategy aimed at maximizing profits, for example by interspersing small amounts of food crops such as yam with cash crops. The food crops would then be used to feed the family throughout the year, or supplement the food supplied by the main provider; the household head. On the other hand, more mature framers with larger families generally prioritized household food security, and thus allocated most of their land to the production of staple crops. Such farmers would often estimate the amount needed to feed their families, and then sell the reserve as cash crops. Nevertheless, in case of low yields or other unforeseen shocks, food crops would be sold, thus compromising the self-sufficiency of farmers. Maize, yam and cassava (*Manihot esculenta*) were the preferred food crops while rice and soybean were cited as the main cash crops. Small amounts of millet (*Pennisetum glaucum*) were cultivated by 'Medium farmers' too. Fields were prepared using hoes, cutlasses, animal traction (Fig. A3-D) and tractors hired out from the 'Big Farmers' (Type A). Post-harvest storage of grain in smaller traditional storage facilities (*kuchung* or *pupuri*) enabled farmers to save food for later consumption, while surpluses and market produce were kept in bags, ready for sale towards the end of the season when prices were highest. Larger households capitalized on the family labour pool, as well as the traditional exchange labour networks. In general, where labour was hired, it was on a smaller scale than that of 'Big Farmers' (Type A), at 4-15 persons a season.

Besides contributing to food for the household in times of need, cash generated from crop sales was used for the payment of school fees, inputs and tractor services as well as motorbikes for transport. Most income, however, was invested in livestock. Typically, 'Medium farmers' did not have much livestock to begin with, but farmers could expand their herds if they managed to avoid selling their animals, ultimately accumulating enough wealth to graduate to the 'Big Farmer' (Type A) category. Farmers possessed up to 20 head of cattle, although those producing more food- than cash crops purchased fewer animals. If livestock were sold, it was because an animal was old or sick, or there was an urgent need for cash and no crops were available to sell first. The only animals bred for sale were pigs, as they were considered to be prolific breeders. However, due to the prohibition of pork consumption among a largely Muslim populace, the market was limited to a small Christian minority. Off-farm, members of this category engaged in a number of artisanal activities to support their livelihoods, such as weaving and selling of traditional *zanna* mats and *gabga* rope (Fig. A3-F), tailoring of clothes and fitting of bicycles. Those who owned donkey carts fetched water from nearby dams to sell in the communities, while others collected and sold firewood, thatching grass and sticks for fencing. Some farmers engaged in small-scale food trade and transportation.

Type C. Pukparbihi ('Small farmers, men'): LRE, subsistence orientation

This type constituted the largest group in Tingoli, as in Kpalung when combined with 'Small farmers, women & children' (Type D). In Botingli, however, it was not considered to be a large group. Overall, 40% of the survey respondents across the three communities were classified as 'Small farmers (men)'. The farm type was distinguished by its relatively small cultivated areas ranging from 0.4 to 2 ha. The main crops grown were maize, sorghum (*Sorghum bicolor)*, cassava and peppers (*Capsicum chinense*). A strategy of allocating the majority of farmland to food crop cultivation was pursued in order to secure household food security. Despite this, food self-sufficiency was rarely achieved. What limited crop surpluses (*e.g.* groundnuts (*Arachis hypogaea*) or peppers) were available would be dried and stored in jute sacks in the compound of the household head and sold; mainly to support purchase of inputs for farming and food for consumption (Fig. A3-I). Especially during the lean season, farmers would be forced to purchase staples such as yams from the market or borrow from neighbours and other community members. Tractor services were rarely hired out by 'Small farmers (men)'- most field preparation and labour was carried out manually with a hoe and cutlass. Farmers applied fertilizer but reportedly not at the correct time due to insufficient funds, with low yields as a result. It was reported that a common scenario for maize was a timely first fertilizer application but a delayed second application due to lack of cash. To mitigate this problem, farmers sold their matured cash crops, such as groundnuts, and used the income to purchase more fertilizer, or borrowed money for the fertilizer itself in order to carry out the applications on time.

Family size- and composition were variable in this category. Small families (2-5 persons) headed by junior, newly independent household heads, were common. As family size and assets grew, such farmers commonly graduated to the 'Medium' (Type B) or 'Big farmer' (Type A) classes. In the case of larger households (>10 persons), it was reported that some were in fact previous members of the 'Big farmer category', but due to crop failure or other shocks, were temporarily reduced to cultivating smaller areas the following season. In other cases, the pressures of large family sizes were instrumental in the household's devolvement to 'Small farmer (men)' status: as family demand for food was higher than what was harvested, this meant that surpluses became unavailable for sale thus compromising future investment into the farm, resulting in a gradual decline in the cultivated area. Household income was generally spent on food and farmers invested in cheap modes of transport such as bicycles. Children of 'Small farmers (men)' were often denied the opportunity of formal education, due to unaffordable school fees.

This farm type depended on family labour and the exchange labour network. Most 'Small farmers (men)' could not afford to hire in labour themselves, but occasionally sold their own labour to make ends meet. In fact, this category also included most of the migratory farmers (youth) who travelled south in the off-season to sell their labour during the first cropping season in Southern Ghana from March-May[5]. Besides seasonal farm work, other off/ non-farm activities pursued by 'Small farmers (men)' included those practiced by 'Medium farmers' (Type B). In general, it was difficult for 'Small farmers (men)' to accumulate small ruminants and cattle. Nevertheless, it was not unheard-of for them to own some livestock and slowly expand their operations. Such farmers had, for

[5] Southern Ghana has two rainy seasons (first season from March-July and second season from August-November). Migrant youth from the North travel down south from February to May to sell their labour during the first season in the south and return back to the North to start their farming which starts in June (Marchetta, 2013).

instance, inherited a few head of cattle from their fathers. Sometimes farmers accumulated larger poultry flocks (Fig. A3-J) but more often the birds were sold quickly for cash or food. In a good year, farmers purchased a few more animals or at least refrained from selling those that they had.

Type D. Pagba pubihi ('Small farmers, women & children'): LRE, SRC, market orientation

This was identified as being the largest category in Botingli and Kpalung (in the latter combined with Type C). In Tingoli it was explained that not all the women were involved in agriculture due to land scarcity, hence the relative small size of the category there. Because only male household heads were interviewed for the survey, no respondents were reported as being representative of Type D. This category concerned the women of the community who were generally married, and their small children. The women and children thus worked together and were part of a larger household. The areas cultivated by women in the study area were between 0.1 and 0.4 ha, with individual farms often located some distance from the compound, out in the bush close to the outfields belonging to the household head. Groundnuts, okra (*Hibiscus esculentus*), soybeans, maize, sorghum, peppers, local leafy vegetables, tomatoes and cowpeas (*Vigna sinensis*) were grown (intercropping was common), yielding a small but diverse harvest. Women reportedly applied compost (Fig.A3-K) to their fields, especially on pepper plants. Yam and millet were considered to be labour intensive crops and their cultivation was reserved for men. With the responsibility of food provision lying with the male household head, women farmed with the objective of selling the majority of their crops. Generally, only the peppers, okra and groundnut were processed and partly consumed. The wives of the 'Medium farmers' (Type B) and 'Big farmers' (Type A) channelled income from crop sales into the purchase of personal items but the wives of 'Smaller farmers (men)' (Type C) forewent these luxuries in favour of investing in household necessities such as spices to supplement the food provided by household heads, and other basic necessities such as the education of their children. Most women also stored some of their produce in jute sacks and pots to sell for inputs (such as seeds) for the next season.

In all the communities, children were reported to be involved in agriculture. Boys learned how to farm on a small plot next to one of their father's fields or out on their mother's field if land was limited. Once adolescence was reached, boys were taken by their fathers to help out on bigger farms until they were married and could inherit land for themselves. Girls helped their mothers with all farm-related activities. Once married, girls were given a small plot by their husbands. Women and children accumulated as many as 10 small ruminants and some poultry, purchased with cash from crop sales. Fowls were sold for cash as needed. Especially boys were encouraged to sell their produce and invest in livestock, with which they could help secure a good marriage partner in the future. As a rule, women did not possess any cattle, nor did they keep guinea fowls, as these had a reputation for being too wild and unruly. Women did not belong to any major exchange labour networks but they hired 2-4 people per cropping season to help out on the farm as needed. In Tingoli it was reported that some women hired out tractor services for field preparation, but in the other communities the use of hoes and cutlasses was the norm. In addition to maintaining their own farms, women were responsible for helping with the planting, harvesting, threshing and winnowing duties on men's farms, often as hired labour or in return for a part of the harvest. Furthermore, women were involved in a number of non-farming activities as part of their livelihood. These included shea butter extraction, processing and sale, small-scale food trading (Fig. A3-G and A3-H), firewood and charcoal collection for sale and household use, soap-making and processing of groundnuts into cakes and oil. Sales were made within the community and at local markets; held in six day cycles.

Type E. Suhukpion ('Farm-less, men'): work on other farms as hired labour

Described as 'farmers who only farm for others for money but have no farm themselves'; this category was only identified in Tingoli and was considered to be the smallest, comprising a few men in the community (none of them were included in the survey). It was explained that Type E representatives were 'farm-less' by choice. Farming members of the community considered such men to be socially deviant as they voluntarily chose not to engage in cultivation of their own farms- the hallmark of a 'true' Dagomba man. They were labelled as 'parasites' with a 'different aim from normal human beings'. Men of all ages could be found in this category. They generally remained unmarried, had no legitimate children and specialized in working as hired labour on other people's farms within the community and beyond. Off-season they worked in masonry and construction or migrated to find work as seasonal labourers on farms in the South of Ghana. Considered to be 'big spenders', they did not own or accumulate any livestock, but instead used their wages on food and personal items of luxury. In many cases, however, they were sheltered and fed by the senior household head of the extended family within which they were embedded, and were known to borrow money when seasonal labour demand was scarce.

Figure A3. *(A) Women pounding boiled yams to make the staple food fufu; (B) A 'Big farmer' household head on his soybean (cash crop) farm; (C) A large, raised kambona (post-harvest storage facility); (D) A pair of draught oxen; (E) Tractor outside a household compound; (F) Farmer-craftsman demonstrating how to make gabga rope; (G) Small-scale trading in dried okra at the local market; (H) Small-scale trading in yams at the local market; (I) Pepper harvest set out to dry before being stored for later sale/ consumption; (J) Poultry flock of local chickens and guinea fowl; (K) Compost pit; (L) Maize harvest.*

Photo credits: Katja Kuivanen

Annex 4A

Focus Group Discussion Tool

Protocol

- Introduction to Chief
- Introduction to FGD participants: project, aim of discussion (*5 minutes*)
- Validate local farm types (*20 minutes)* - see Annex 4A.1
- Discuss status of and factors for implementation of the different AR technologies (*40 minutes*) – see Annex 4A.2
- Discuss intra-household (farm type) dynamics (*10 minutes)* – see Annex 4A.3
- Thank the participants and hand out gifts (*5 minutes*)

Total duration of Focus Group Discussions: 1 hour and 20 minutes

Annex 4A.1

<u>First part of the Focus Group Discussion</u>: Validation of Farm types *(20 minutes)*

Questions to the communities are marked bold. Remainder: context/narrative

'We (Africa RISING (AR)) have done household surveys. A household is defined as a 'production and consumption unit', mostly encompassing family members but also permanent hired labour. A household member is a person who regularly contributes money and/or labour and/or who receives money and/or farm products from the same land and livestock resources.

Within the household, the members have different responsibilities, farming different fields with different purposes *e.g.* men are responsible for food security (growing maize) while women farm vegetables (*e.g.* okra, tomato).

With this research we would like to better understand how local farming systems work.

First question to the group: **does a household form a farming unit** (exchanging labour and resource, being dependent on each other for making decisions) **OR are the individual members autonomous/independent farm businesses** (*e.g.* do women run separate farming units from men, they do not receive inputs and can make their own decisions)?

Why are we asking this: during the participatory typology construction communities grouped individuals (male HH head, wife, landless people) rather than entire households. We would like to understand if we should continue modelling whole-farming systems at household level or if the components (fields, livestock) are in fact managed separately by individual household members and hence would also have to be modelled separately.

Answer:

If households are a valid unit of analysis we would like to visit, during the coming days, 3-4 households in your community to get more information on their farming practices. We would not like to visit 3 of the same households but different ones. We thought of asking farmers of different resource endowment (*e.g.* some farmers with little land and few animals, some farmers with a lot of land and a lot of livestock).

Second question to the group: **are land size and number of animals good indicators for differentiating farm households?**

If not, what indicators should be used to 'group' households?

If yes, are there additional factors that should be considered?

Answer:

Based on the indicators you just mentioned, could you please describe the 3-4 main farm types that can be found within this community.

Farm type	Indicator 1:	Indicator 2:	Indicator 3:	Indicator 4:	Indicator 5:
1					
2					
3					

Can you give a few examples for households (names of HH heads!) in this community who would exactly fulfil the criteria of a type respectively?

Farm Type	Names:
1	
2	
3	

Even if households are a good unit of analysis, there are typically differences in roles, interests and power among different household members. Is that correct?

If the statement above is correct: to understand all the different views within a household who would typically have to be consulted? *E.g.* the male HH head, the female HH head, the wife, the oldest son, the oldest daughter, children above which age?

Answer:

Annex 4A.2

Focus Group Discussion Tool

Factors for and Status of Adoption *(in total: about 40 minutes)*

What is the status of adoption of the different AR-technologies within this community? *(5 minutes)*

ID	AR tech's	Status of Implementation **among AR-participants (HHs)** *% of households that have implemented it (e.g. 20% at 1 acre level, 40% as a baby trial, 10 % mother trial and the remainder not at all)*	Status of Implementation **in the community** *% of farmers that have implemented it (e.g. 20% at 1 acre level, 40% as a baby trial, 10 % mother trial and the remainder not at all) = measuring spill-over effects*
1	Optimized Nitrogen Rate on Maize (NR, UE, UW)		
2	ISFM on Soybean (NR, UE, UW)		
3	Optimized Spraying of Cowpea (NR, UE, UW)		
4	Maize Groundnut Rotation (UE, UW)		
5	Maize Cowpea Rotation (UE, UW)		
6	Maize Soybean Rotation (UE, UW)		
7	Maize-Groundnut Strip Cropping (NR, UE, UW)		
8	Maize-Soybean Strip Cropping (NR, UE, UW)		
9	Maize-Cowpea Strip Cropping (NR, UE, UW)		
10	Feed and Health Package for Livestock		
11	Other:		

Who is interested in/benefits from the AR-technologies? Who could be against it and why? *(8 minutes)*

ID	AR tech's	**Who is (interested in) implementing it?** *Describe characteristics of individuals or farm types*	**Who did not adopt or is against it?** *Describe characteristics of individuals or farm types*
1	Optimized Nitrogen Rate on Maize (NR, UE, UW)		
2	ISFM on Soybean (NR, UE, UW)		
3	Optimized Spraying of Cowpea (NR, UE, UW)		
4	Maize Groundnut Rotation (UE, UW)		
5	Maize Cowpea Rotation (UE, UW)		
6	Maize Soybean Rotation (UE, UW)		
7	Maize-Groundnut Strip Cropping (NR, UE, UW)		
8	Maize-Soybean Strip Cropping (NR, UE, UW)		
9	Maize-Cowpea Strip Cropping (NR, UE, UW)		
10	Feed and Health Package for Livestock		
11	Other:		

What factors generally determine the adoption of AR-technologies by the different household types? (5 minutes)

Source from this list of possible discriminators:

0 = not important, 1 = low importance, 2 = medium, 3 = high importance

Household type	Cost	Labour	Acceptability	Accessibility	Ease of application	Increase of yields	Improvement of soil fertility	Improvement in product quality	other (namely):	other (namely):
1 LRE										
2 MRE										
4 HRE										

What are concrete reasons for adoption or non-adoption of each AR-technology per household type? *(8 minutes) Write A or NA, then give reasons*

ID	**AR technology**	**Type 1: LRE**	**Type 2: MRE**	**Type 3: HRE**
1	Optimized Nitrogen Rate on Maize (NR, UE, UW)			
2	ISFM on Soybean (NR, UE, UW)			
3	Optimized Spraying of Cowpea (NR, UE, UW)			
4	Maize Groundnut Rotation (UE, UW)			
5	Maize Cowpea Rotation (UE, UW)			
6	Maize Soybean Rotation (UE, UW)			
7	Maize-Groundnut Strip Cropping (NR, UE, UW)			
8	Maize-Soybean Strip Cropping (NR, UE, UW)			
9	Maize-Cowpea Strip Cropping (NR, UE, UW)			
10	Feed and Health Package for Livestock			
11	Other:			

Possible reasons (source from this list):

Household Composition	*Labour availability, Gender of HH head, Educational level, Religion, Off-farm income...*
Farm Resource Base	*Total land size, Current Soil Fertility, Soil Erosion*
Technology Features	*Cost of inputs, Access to inputs, Labour requirements, Low or high level of knowledge/skills required, potential yield improvements, potential improvements in soil fertility, potential improvement in product quality*
Community	*Social cohesion, personal contact to model farmer (personal recommendations and impression)*
Production Orientation	
Market Access	

How important (for technology adoption) are the following aspects typically for the different household members? *(8 minutes)*

0 = not important, 1 = low importance, 2 = medium, 3 = high importance

Household member	Cost	Labour	Acceptability	Accessibility	Ease of application	Increase of yields	Improvement of soil fertility	Improvement in product quality	other (namely):	other (namely):
Male HHH										
Female HHH										
Wife I										
Wife II										
Sons (Age:_)										
Daughters (Age:__)										
Other:										
Other:										
Other:										
Other:										
Hired perm. labour										
Landless										

What are the motivation/drivers/reasons for or against the adoption of the AR-technologies for each household member? *(10 minutes)*

AR-technology	Male HHH	Female HHH	Wife	Other:	Other:	Other:	Other:
Optimized Nitrogen Rate on Maize							
ISFM on Soybean							
Optimized Spraying of Cowpea							
Maize Groundnut Rotation							
Maize Cowpea Rotation							
Maize Soybean Rotation							
Maize-Groundnut Strip Cropping							
Maize-Soybean Strip Cropping							
Maize-Cowpea Strip Cropping							
Feed and Health Package (Livestock)							
Other:							

Possible reasons (source from this list):

Features of HH members	*Age, gender, Health Status, Pregnant/Lactating, Education, Marital Status, Religion, Access to land, labour availability, off-farm income*
Feature of Product	*Destination (cash crop or home consumption), improvements in yields, improvements in soil fertility, improvements of product quality, market price, nutritional value, crop as a social/status symbol*
Field Characteristics (as managed by the particular HH member)	*Field Size, Soil fertility/erosion, Soil type, Land tenure status (rented or owned), heritage of land (where crops are grown), Distance of fields to homestead, Distance of grazing grounds to homestead*
Tools and Tasks	*Health Risk (e.g. by chemical spraying), Physical intensity of labour, technology level, knowledge required, skills required, timing of tasks, total labour requirements*
Community	*Norms and traditions, relation to immediate neighbour, social cohesion, personal contact to model farmer (personal recommendations and impression)*
Market Access	

Annex 4A.3

Focus Group Discussion Tool

Inter-Household Dynamics

- Are there a few individual households that can be considered 'leaders' and others 'followers'?
- Is there a 'tipping point' (*e.g.* if 20 % of the community adopts a technology, the rest of the community will follow soon after)?
- What are the factors that make a technology spread in a whole community (what does the technology have to offer? List main characteristics in order of importance)

Farm type specific:

- If farmer of type A is assisted in getting higher yields and he or she achieves this, does this motivate farmers of other types to search for their own strategies? Is it rather a pressure (pull) than a motivation (push)?
- How could one type evolve into another (reflection)?
- What would be the impact on each type if all the AR targets (to increase yields and soil fertility *etc.*) are achieved?

Annex 4B

Table A4.1. *Description of low, medium and high resource endowed farm households per community (Duko (NR), Nyangua (UE) and Zanko (UW)) based on FGDs with farmers of the same community.*

Farm Type	Land Size (hectares)	Animal Number and Type	Roofing Material	Means of Transport
Northern Region				
LRE	0.8-1.2	Few poultry	Thatch	Bicycle
MRE	2	No cattle	Mixed	Motorbike
HRE	4-6	Cattle, many small ruminants	Zinc	Motorbike(s)
Upper East				
LRE	0.4	Some poultry	Thatch	On Foot
MRE	0.8 – 1.2	Some poultry, small ruminants	Mixed	Maybe: bicycle
HRE	2 or more	Cattle, small ruminants, poultry	Zinc	Motorbike
Upper West				
LRE	2	Poultry	Zinc	Bicycle
MRE	<4	Poultry and small ruminants	Zinc	Motorbike
HRE	>4	Cattle, small ruminants, poultry	Zinc	Motorbike(s)

Annex 4C

Farmer survey. Excel file. Accessible online at: https://doi.org/10.1016/j.agsy.2018.01.028

Scan QR code to access the link:

Annex 4D

Detailed model assumptions concerning P1-P5

Tailor-made implementation of Africa RISING technology packages per farm in FarmDESIGN

Background

Based on in-depth farmer interviews we constructed a model for each farm in FarmDESIGN, describing their actual/current farm configuration. At the time of the farm interviews (December 2015) farmers (different household members) had already partially adopted and adapted the different Africa RISING packages. In order to determine the effect of the AFRICA RISING packages we reset each farm to a baseline (with traditional practices; recreating the farm 'before Africa RISING'). The traditional practices for maize, cowpea and soybean cultivation are described in Table 2 of the article. If farms *e.g.* already used improved (maize) seeds, higher amount of Sulphate of Ammonia (SA) or a higher number of sprays for cowpea than the traditional practice, we adjusted the levels downwards to our reference scenario, making the impact of P1-P5 more visible and more comparable among the different case-study farms. If a farm however used less seeds, sprays and fertilizer than the traditional reference we did not adjust it upwards since the Africa RISING package would in fact have a greater impact on such a farm than on others.

The impact of the technology packages also differed based on the area available for the implementation of the different packages as well as the nature of their labour figures at baseline:

To provide an example for the impact of current labour figures: if total labour inputs (hours/year) are generally low, even small increases may have a significant negative impact. If total labour inputs are high, even larger increases, such as for P3 (ISFM on soybean), have a low relative impact.

Concerning the impact of spatial extents per package: if a farm household is not land constrained, new crops, such as soybean in P3, are assumed to be grown on an additional piece of land, not compromising or altering the existing farm activities. Resource (land, labour) constrained households might however not be able to expand their farm area or grow an additional crop without compromising an existing activity. For resource constrained cases we *e.g.* typically assumed soybeans to substitute cowpeas on the same land area. In August 2016 we revisited all nine case-study farms to validate our assumptions. Corrections have been made, consolidating our technical analysis (the models in FarmDESIGN). By allowing different spatial extents per technology package per farm, the results among packages and farms become less comparable. The implementation of the packages, however, had to be achievable for each individual case-study farm, otherwise our assumptions would not be realistic and our results would not be meaningful.

The assumptions as listed below are also presented in the notes in the FarmDESIGN model. Farmer feedback to the general model assumptions is mainly based on statements of the household head (HHH). If anything is NOT mentioned in the assumptions, the standard reference values of Table 2 were used (*e.g.* inputs, seed type and rate for P3 *etc*.). Additional labour requirements (for implementing P1-P5) are assumed to be covered by household labour force. Household labour force (in the model expressed as 'regular labour') has the same price (in the model) than hired labour, so economically it does not make a difference. Since we do not alter the livestock components when simulating P1-P5, we exclusively analyse changes in 'crop labour'- inputs by the household in order to evaluate changes in labour per technology package. We however had to adjust the feed balance for each scenario, see section on 'the feed balance' below.

How to read the notes in FarmDESIGN

The values entered in the FarmDESIGN model are based on literature references, expert information or farmer surveys. The exact source is indicated for each item in the notes. The notes are structured with more specific information on the top and more general information at the bottom (since the more general information is shared among other farms or scenarios and the more specific information builds on it). The notes also contain assumptions and calculations.

Some crop entries under ‘crops’ display a ‘0’ or ‘RESET’ in front of their denomination, indicating that in the scenario at hand this crop has an area of 0 or was reset from being an ‘Africa RISING’-field (under strong influence of Africa RISING practices) to a status ‘before Africa RISING’.

The feed balance:

The most important reference point for the feed balance is the ‘baseline’ farm configuration: based on farmer statements we allocate a certain share of the farm crop residues to animals (*vs.* its use as green manure). We then use imported organic matter (such as external grazing grass, maize stalks (based on free range) or milling waste) to compensate for any deficiencies. When we model the different scenarios (P1, 2, 3, 4 and 5) crop yields and hence the feed supply changes. The feed provision must meet the existing demands, adding up to the feed balance. For the feed balance we set constraints, namely:

DM	Energy	Protein	Structure
-100	-5	0	100
0	+5	30	1000

Only if the values of the feed balance are within these constraints the farm (model) is ready for an exploration.

For all five packages, crop yields increase, translating into an over-supply of residues according to the baseline feed balance. For each scenario, we hence first try to balance the feed by reducing the import of expensive organic matter such as maize bran (especially for P1, P4 and P5, which include an increase of maize yields). Next, we reduce the amount of residues (of those crops whose yields increased) fed to animals and increase the amount used as green manure, keeping the residues on farm, but re-allocating them. If residues of higher value (*e.g.* cowpea as compared to maize) become more available, we reduce feeding lower value residues such as maize stalks (assigning more of the stalks as green manure).

It is also important to note that we separated the feed balance of ruminants (in feed balance under 'grazing') and non-ruminants (under 'stable'). While non-ruminants (poultry) are typically free range in and around the homestead (barn and yard, see 'whereabouts'), ruminants graze on crop stubbles and pastures, so that feed grain for ruminants (of lower quality than food grain) and maize bran are assumed to be purchased if needed. Although poultry is likely to get a lot of feed resources 'for free', we valued feeds (*i.e.* we gave it a price) in order not to distort the picture during the exploration and to make them visible/valuable in the system.

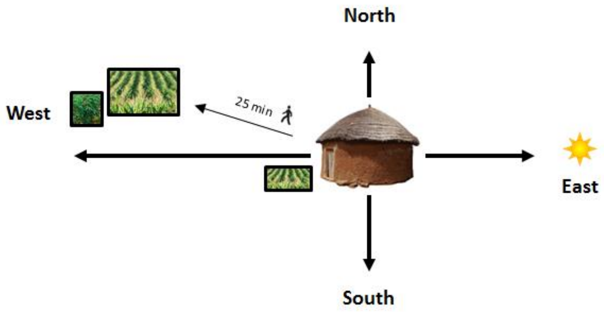
Choice of legume type for the rotation

The type of legume for the rotation is chosen based on the performance of P2 (cowpea) as compared to P3 (soybean) in the model, which proved to be a reliable indicator of the performance of cowpea versus soybean in the rotation (P4) and strip crop (P5). We used labour, SOM and profits as performance indicators and chose the crop (cowpea or soybean) that evinced a better performance when comparing P2 and P3.

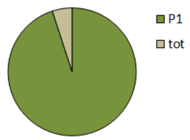
Northern Region (NR)

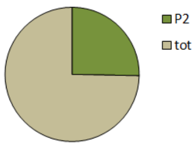
Farm #1: Low Resource Endowed (LRE) household

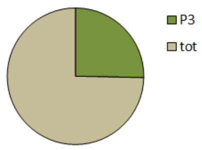
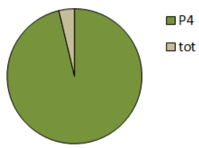
Context:

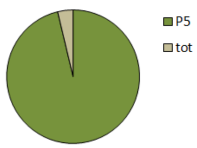


Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**
1.6	480	520 + 7	-380

	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 1.52 Maize yield (kg/ha): 818 Labour (h/ha): 330.2 Seed type: recycled Seed rate (kg/ha): 5 NPK (kg/ha): 63 SA (kg/ha): 0	We assume that all maize fields are grown according to P1 recommendations: Fertilizer: 247 kg/ha NPK (15:15:15), 247 kg/ha SA (total: 60 kg of N/ha) Seeds: Improved seeds (cost 3.3 GHS/kg), 21 kg/ha, row planting Average additional labour: +2.5h/ha; Concerning the yield increase: This household currently applies 63 kg/ha NPK and no SA, hence the yield increase is expected to be greater than the reference (25%). The wife has an Africa RISING P1 Baby trial (15x15m), achieving yields of 4013 kg/ha, corresponding to a yield increase of 391 %. When implemented on a	The household head (HHH) and the wife (separately) confirmed that he would like to grow all of the maize according to P1 recommendations. The HHH stated not to be able to afford the full recommended fertilizer rate, despite him being convinced of its benefits. He is practicing the affordable aspects of P1 such as row planting. The wife confirmed, they would apply only half of the rate of fertilizer in 'reality'.

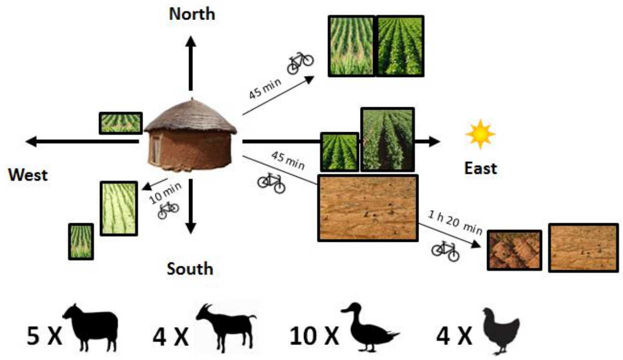
		larger area we expect the increase to be lower. We assume a yield increase of 150%. P1 maize yield = 2044.25 kg/ha	We continue to work with the standard P1 assumption (247 kg/ha NPK, 247 kg/ha SA) adding a note that this household is not able to make the investment at this moment (= technical option currently not attainable/affordable)
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): - Cowpea yield (kg/ha): - Labour (h/ha): - Seed type: - Seed rate (kg/ha): - Sprays: -	In order to introduce cowpea, we reduce the maize area to a level that still sustains the households maize needs (amount home consumed at baseline). 1.1386 ha needed to produce 913 kg (817.7 kg/ha). Cowpea area: 0.4025 ha Reference yields (other case-study farms): 766 kg/ha - 1030 kg/ha. Since the household head indicated that the yields of this household are typically lower than those of other households in the community we assume cowpea yields of 700 kg/ha. Since this is the reference yield and according to P2 the yields would increase by 45 %, we determine a yield of 1015 kg/ha for the Africa RISING cowpea plot. Cowpea assumed to mainly be sold (90%), due to its higher market price than maize. Other farms used on average 259 hours/ha for cowpea. P2: +6.23 hours/ha --> 265.23 hours/ha. Seeds: 20 kg/ha (cost: 6.7 GHS/kg)	When we revisited this household in August 2016 the farmer (HHH) indicated that he has never grown cowpea before (<u>no reference point available for yields and labour</u>). and that, if he grew cowpea, he would use it mainly for home consumption. Since cowpea fetches a much higher market price than maize (cowpea: 980 kg/ha * 2.03 GHS = 1989 GHS/ha; maize: 728 GHS/ha) we nevertheless assume high cowpea 'sales' keeping 10% for home consumption. <u>Residues will be eaten by animals of other farmers</u> (in the future: maybe the own animals). The HHH confirmed that the <u>labour requirements for cowpea are lower than those for maize</u>. The wife added that they would plant in straight lines. They would spray 3 times. So yes, they would apply this on all fields and if they could not: they would rather reduce the area of cowpea.
P3	Soybean Area (ha): - Soybean yield (kg/ha): -	Same area as for cowpea in P2: 0.4025 ha. Yield: Reference yields (other case-study farmers):	When revisiting the household in August 2016 the HHH and the wife confirmed that this household would grow soybeans

 *Areal extents (tot =remainder to total farm area)*	Labour (h/ha): Seed type: - Seed rate (kg/ha): -	315 kg/ha - 662,4 kg/ha (average of 442kg/ha) Mother trial yields: 740 - 807 in Duko for farmer practice ('ISFM 1'). For the whole Northern region, the yield average for 'ISFM 1' are 730 kg/ha (year 2015) and 1210 kg/ha (year 2014). We decide to work with the 'farmer reference yield'. It must be noted that in the year of recording (2015) the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). Since this farmer (HHH of NR LRE HH) indicated that the yields of this household are typically lower than those of other farmers in the community we assume soybean yields of 400 kg/ha for this farm household. Since this is the reference yield and according to P3 the yields would increase by 50 %, we determine a yield of 600 kg/ha for the Africa RISING soybean plot. Use: Soybean assumed to be mainly sold (90%). Labour: Other farms used on average 709 hours/ha for soybean (HH1, HH2 and HH7). Hence this figure is assumed and we add 18 hours/ha (as defined in package 3) = 727 hours/ha.	mainly for the purpose of selling it. He thinks however that this package is expensive, since the inputs for it are expensive. The wife also mentioned the good value during sales. She likes soybean since one can prepare many dishes from it. She mentioned that labour for harvesting can be a challenge, since there is a narrow time window for it. If the household runs out of labour during this time, then the crop will shatter. They are limited by their labour availability. She also needs a plastic sheet ('tampolin') for threshing. This household does not own one, so she needs to wait until other households have finished using it, so that constitutes a constraint, Soybean they plant in straight lines, but they would not have enough money to purchase certified seeds or fertilizer.
P4  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): 1.525 Legume Area (ha): - Maize yield (kg/ha): 818 Legume yield (kg/ha): -	Legume chosen: Cowpea Reason: Higher yield, good price, less cost, less labour than soybean Area: We chose a 1:1 rotation, with 0. 770625 ha of maize and cowpea each. We had calculated that an area of 0.770625 ha for maize (at 50% higher yields as compared to the baseline) will supply this household with the 'necessary' (baseline) amounts of maize grain. We hence assume a rotation of 0.770625 ha of maize with 0.770626 ha of cowpea. Concerning maize:	For a rotation the HHH indicated to prefer cowpea over soybean. This is in line with our model assumption. The wife also stated that she would prefer cowpea for the rotation (or the strip).

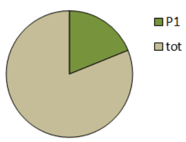
		Yield: Maize yields increase by 50 % (sole maize after maize) 817.7 kg/ha * 1.5 = 1226.56 kg/ha Labour: For the maize area the recommended fertilizer rate of 2NPK and 1SA is assumed. Labour slightly increases for row planting (+1 hours/acre for maize (2.47 hours/ha) for maize-cowpea). 330.2 hours/ha + 2.47 hours/ha = 332.67 hours/ha Concerning cowpea: According to the AR protocols (on maize-cowpea rotation) cowpeas should be sprayed twice. We assume a slight improvement in yields as compared to the determined reference yield of 700kg/ha (based on achieved yields by other farmers), hence we assume a yield of 750 kg/ha for cowpea. Use: Same amount of the cowpea grain is kept for home consumption as assumed in P2: 25.4 kg DM. Labour: 259 hours/ha + 5 hours/ha = 264 hours/ha	
P5  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): 1.525 Legume Area (ha): - Maize yield (kg/ha): 818 Legume yield (kg/ha): -	Same as above, except for higher labour requirements as described in Table 2 of the article.	The HHH stated that P5 is more labour intensive due to the necessary demarcations in order to correctly plant the different crops together. Our translator in Duko (in August 2016) reported that a pre-emergence spray was used in the strip crop. No information is available about this from the protocols nor from other farmers so this will not be considered it in FD.

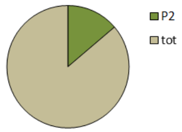
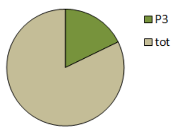
Farm #2: Medium Resource Endowed (MRE) household

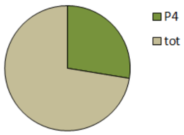
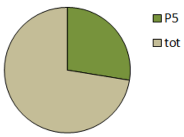
Context:



Area (ha)	Profit (GHS/yr)	Labour (hours/yr) household + hired	SOM (kg/ha)
10.3	2242	1975 + 1189	-693

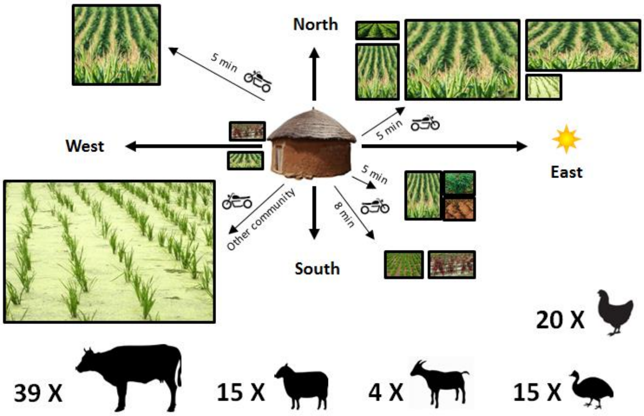
	Baseline	Assumptions	Farmer Feedback
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 1.944 Maize yield (kg/ha): 399.5 Labour (h/ha): 418.3 + 17.2 hired Seed type: recycled Seed rate (kg/ha): 15 NPK (kg/ha): 205.8 SA (kg/ha): 0	Area (ha): 1.944 (the only maize field is now assumed to be grown according to P1) Yield increase: + 150% (similar starting grounds than the LRE farm) New yield (kg/ha): 998.75 Use: Same amount (464 kg DM) home consumed as in the baseline; the remainder is sold Labour (h/ha): +2.5 hours/ha --> 420.8 hours/ha (household = regular)	When we revisited this household in August 2016 the HHH stated that he would like to continue growing some local maize beside. This means that this household will not transform all of their maize field to P1! They will probably, however, incorporate some 'Africa RISING practices' such as row planting into their traditional maize field. The HHH stated to recycle seeds. He does not buy new ones. This was confirmed by his son and the wife. The son stated that the HH uses 123 kg/ha od NPK and 123 kg/ha of SA. We still assumed a full implementation of the P1 package to see what would be the 'theoretical impact' of it on this

			farm *e.g.* compared to the LRE farm in the same community. Note: Surprisingly this household has considerably lower yields than the LRE household (in maize). Maybe it is because the LRE household almost exclusively focuses on maize, depending on it for their food security while the MRE household grows a variety of crops and keep animals, so maybe this results in less commitment to (maize/crop) management practices.
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): 1.42 Cowpea yield (kg/ha): 581 (son 20, 22), 746 (son 29) Labour (h/ha): 142 + 54 hired Seed type: improved Seed rate (kg/ha): 15 (son 20), 18 (son 29) Sprays: 1	This farm has 3 cowpea fields. We assume that the AR-suggestions are implemented on all of them. Based on Kotu et al. (2016) we assume a yield increase of 45% in cowpea grain when compared to traditional practices. Area (ha): 1.42 Yield (kg/ha): 843.03 kg/ha (son 20, 22) 1081.7 kg/ha (son 29) Use: 139.5 kg DM of son (20 and 22) for home consumption, remainder sold 281 kg DM of son (29) for home consumption, remainder sold Labour (h/ha): 144 (household = regular) + hired (54)	When we revisited this household in August 2016, our assumptions were confirmed by the HHH and the son: all three cowpea fields could be 'set under P2'.
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): 1.83 Soybean yield (kg/ha): 300 (HHH), 476 (son) Labour (h/ha): 446 + 336 hired (HHH) 370 + 90 hired (son) Seed type:	All soybean fields are assumed to be cultivated according to P3. Area (ha): 1.83 Yield increase: +50% Yield (kg/ha): 450 kg/ha (HHH) 714.2 kg/ha (son) Use: all sold Labour (h/ha): +18 hours/ha 464.4 hours/ha (HHH)	When revisiting the household in August 2016 it was reported that the household sells most of the soybean since it is not well aware on what dishes to prepare with it. The son confirmed that the current seed type is recycled, and that no fertilizer or inoculum is used on soybean.

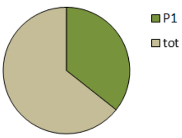
	recycled Seed rate (kg/ha): 14.8		
P4  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): 1.944 Legume Area (ha): Maize yield (kg/ha): 399.5 Legume yield (kg/ha):	Legume chosen: Cowpea Reason: more profitable, less labour, better SOM balance values Area: 1:1 rotation Maize area (ha): 1.42 Cowpea are (ha): 1.42 Concerning maize: Yield: + 50% --> 599.3 kg/ha Labour: + 2.47 hours/ha = 421 hours/ha Use: 464 kg DM home consumed, remainder sold Concerning the legume: Yield: 766 kg/ha (son 20 and 22= actual/current; 2 spays) 1030 kg/ha (son 29 = actual/current; 2 spays) Labour: + 5 hours/ha Use: same as P2	When we revisited this household in August 2016 the HHH stated that he would rather chose soybean for a rotation. In the evaluation, the HHH had however stated that P3 was very expensive, mainly due to fertilizer inputs when compared to traditional practices. It seemed like the HHH, for this question, was thinking of inputs from Africa RISING: if he was to choose whether to get the inputs for cowpea or soybean, he would go for soybean. In FarmDESIGN, cowpea clearly performs better than soybean. In order to stay consistent within the logic of FarmDESIGN we concluded that under the set model assumptions, despite the HHHs preference, cowpea is the choice for the rotation. We asked the HHH whether a rotation is possible, since the different fields (maize, cowpea) belong to different household members and a certain land area is usually managed by the same person with different production objectives. We were told that this did not constitute a problem.
P5  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): 1.944 Legume Area (ha): Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	Same as above.

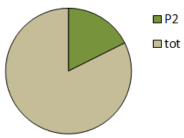
Farm #3: High Resource Endowed (HRE) household

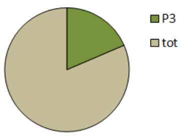
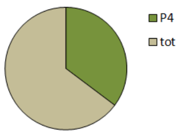
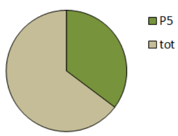
Context:



Area (ha)	Profit (GHS/yr)	Labour (hours/yr) household + hired	SOM (kg/ha)
28.4	12100	11078 + 6833	-479

	Baseline	Assumptions	Farmer Feedback
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 10.125 Maize yield (kg/ha): 1783.7 kg/ha (Adam) 446 (compound field) 787 (HHH) 223 (HHH, cassava) Labour (h/ha): 31 + 207.9 hired Seed type: recycled	The compound maize field and the maize field of Adam are very close to our 'reference scenario' (traditional practice), hence we assumed a yield increase of 25%. The big maize field of the HHH however, uses much less NPK and no SA, hence the yield increase is assumed to be significantly bigger (similar shift than in the LRE and MRE farm in Duko (same community) where we assumed an increase of 150 %). In the 'maize + cassava' field and the 'yam + maize' field maize only grows in between the rows, not fully, so these fields are rather considered yam and cassava fields instead of a	-

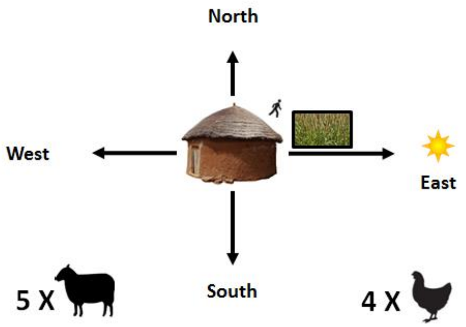
	Seed rate (kg/ha): 5 NPK (kg/ha): 130.72 SA (kg/ha): -	maize field, so we did not implement P1, P4 or P5 on them. BUT we assumed that in the 'maize-related packages; (P1, P4 and P5) residues are not burnt, but used as green manure, as recommended by Africa RISING. Area (ha): all Yield increase: +25% for Adam's field and the compound field +150% for the field of the HHH Yield (kg/ha): 2230 (Adam) 557.5 (compound field) 1967.5 (HHH) Use: the household stated that 20 bags of maize (=1571.22 kg DM) are home consumed, the remainder is sold. Since it is usually the HHHs responsibility to cover these needs we assumed that this amount is mainly provided by the HHH. + son (440 kg DM home consumed) Labour (h/ha): + 2.47 hours/ha	
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): 0 Cowpea yield (kg/ha): - Labour (h/ha): - Seed type: - Seed rate (kg/ha): - Sprays: -	Since this household does not grow cowpeas yet and since they have a significant financial 'cushion' we assume that they would rent in additional land if they were to add cowpea to their existing crops. We assume that they rent in additional 5 hectares. Since this household does not grow cowpeas yet, we take a reference yield from other farms visited (recorded yields range from 766 kg/ha - 1030 kg/ha (sprayed once), the average mother trial yields for cowpea in the Northern Region range between 555 and 1130 kg/ha. This farm evinces average yields, so we assume a 'standard' cowpea yield of 900 kg/ha. Since this is the reference yield and according to P2 the yields would increase by 45 %, we determine a yield of 1305 kg/ha for the Africa RISING cowpea plot. Area (ha): 5 hectares Yield increase: +45% Yield (kg/ha): 1305 kg/ha Use: 90 % sold Labour (h/ha):	When we revisited this household in August 2016 the HHH stated that cowpea grain would mainly be sold.

		Other farmers used on average 259 hours/ha for cowpea cultivation. + 3.7 hours/ha for this package > 262.7 hours/ha - all assumed to be covered by household labour force.	
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): 5.265 Soybean yield (kg/ha): 662.4 (HHH) 315.4 (son) Labour (h/ha): 612.4 + 270.4 hired	Area (ha): 5.265 Yield increase: +50 % Yield (kg/ha): 993.6 (HHH) 473.1 (son) Use: 348.75 kg DM home consumed (son), HHH sells all of the grain produced on his field. Labour (h/ha): + 18 hours/ha = 630.4 hours/ha (HH)	-
P4  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): 10.125 Soybean Area (ha): 5.265 Cowpea area (ha): 0 Yields: see above	Legume chosen: Cowpea Reason: more profitable, less labour, better SOM balance values We assume that the 5 hectares of cowpea that have been added in P2 are now rotated with the maize of the HHH. The HH uses lower amounts of fertilizers, but we merely look at the effect of rotating maize with cowpea (+ 50 % yield, but also + 2.5 hours/ha). Area (ha): 1:1 rotation (5 ha of maize/cowpea) Concerning maize: 5 hectares of the HHH are rotated Yield: +50% --> 1180.5 kg/ha Labour: +2.5 hours/ha Use: 440 kg (son) + (=1571.22 kg DM) are home consumed Concerning the legume: 2 sprays Yield: -20% as compared to P2 --> 1174.5 kg/ha Labour: -0.5 hours/ha Use: 169.7 kg DM home consumed (same as in P2)	When we revisited this household in August 2016 the HHH stated that The first choice for a legume in rotation would be soybean, then cowpea. The wife was also more positive about the P3 soybean package than the P2 cowpea one. In FarmDESIGN (like for the MRE HH), cowpea clearly performs better than soybean. In order to stay consistent within the logic of FarmDESIGN we concluded that under the set model assumptions, despite the HHHs preference, cowpea is the choice for the rotation.
P5  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): Legume Area (ha): Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	Same as above.

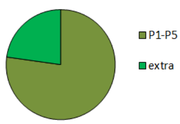
Upper East (UE) Region

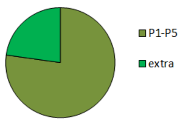
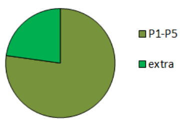
Farm #4: Low Resource Endowed (LRE) household

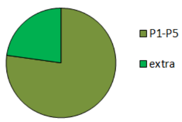
Context:

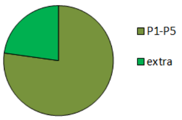


Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**
0.2855	704	141 + 7	753

	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 0 Maize yield (kg/ha): - Labour (h/ha): - Seed type: - Seed rate (kg/ha): - NPK (kg/ha): - SA (kg/ha): -	Area (ha): 0.405 ha Yield (kg/ha): 800 kg/ha (assumed 'baseline) + 25% for P1 --> 1000 kg/ha Use: all home consumed Labour (h/ha): 500	When we revisited this household in August 2016 the female HHH stated that she did grow maize in the past with estimated yields of 674 kg/ha (we calculated that based on an indication of 'bags' she indicated to have harvested). This is however far below the yield of the MRE and HRE household in the same community. We assume that she can go higher, but not AS high as the two other farms, due to her labour constraint. She stated that she would not substitute her existing crops, but that she would allocate an additional 0.405 hectares (1 acre). This is more than her

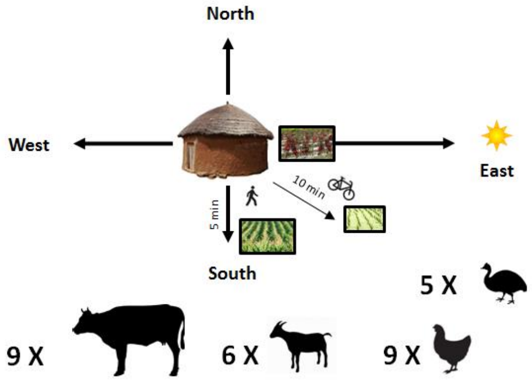
			current total farm area but she stated that this would be realistic. She however does not have any financial means to buy fertilizer, so at the moment it is not worth the effort. So this household cannot afford the inputs, but we would still would like to test what impact P1 would have on her farm.
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): 0.405 (intercrop with millet and roselle) Cowpea yield (kg/ha): 58 kg/ha Labour (h/ha): 110.93 (millet and cowpea) Seed type: recycled Seed rate (kg/ha): NA Sprays: 0	The existing cowpea in the intercrop only yields 58 kg/ha, which is extremely low, probably due to the low seeding rate in the intercrop. We checked the cowpea mother trial data ('farmer practice') for the Upper East. Here average yields of 550 kg/ha are indicated. An additional reference point is the MRE HH in Nyangua, in same community. The baseline cowpea yield is 448 kg/ha (MRE). We assume that the LRE HH has slightly lower yields than the MRE HH, since the LRE is limited in the amount and quality of labour it can get. We hence assume cowpea yields of 400 kg/ha under traditional cultivation. Area (ha): 0.405 ha Yield (kg/ha): 400kg/ha (see explanation above) + 45% (P2) --> 580 kg/ha Use: all home consumed Labour (h/ha): 150 h/ha Explanation: the MRE HH in Nyangua invests 209.86 hours/ha; the HRE HH invests 276.33 as well as 33 hires labour hours. We assume the LRE HH invests 150 hours/ha of own labour.	When we revisited this household in August 2016 the female HHH confirmed that she would be able to cultivate 1 acre extra as compared to her current farm area and that she would get support from her neighbours in terms of labour (provided that she chooses appropriate times for the different tasks, namely times when other farmers are not completely busy on their own farms). The female HHH also stated that she will only buy sprays if she has the improved seeds. Currently she cannot afford to buy the improved seeds so it does not make sense for her to spray. In order to model the effect of P3 we assume that the full package is implemented (despite investment costs probably being too high for her, but that is part of the social counter piece of the analysis).
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): - Soybean yield (kg/ha): - Labour (h/ha): - Seed type: - Seed rate (kg/ha): -	This farm currently does not grow soybean. Similar to the assumptions for P2, we assume that 1 acre is added to the baseline farm area where now soybean is grown according to Africa RISING recommendations (with 60 kg/ha TSP).	When revisiting the household in August 2016 the female HHH stated that she is not interested in cultivating soybean, because it is difficult to cultivate especially while you harvest and if you want to thresh it. If she would nevertheless grow soybean, she would consume the soybean grains, not sell it.

		We assume for P3 that cowpea soybean is grown on 1 extra acre of farm land. Reference yield from other farms (recorded yields range from 315 kg/ha - 662,4 kg/ha (average of 442kg/ha). The mother trial yields range between 920 and 1240 kg/ha. Concerning the farmer reference yields it must be noted that this year the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). However, due to a lack of labour (see explanation below), the attainable yield is assumed to drop to 400 kg/ha Concerning labour inputs: the average labour input of other farmers (in the NR) is 709 hours/ha. We assume that this household can only afford half of this amount, hence 354.5 hours/ha, so roughly 355 hours/ha. Area (ha): 0.405 ha Yield (kg/ha): 400 kg/ha + 50% = 600 kg/ha Use: all home consumed Labour (h/ha): 355 h/ha+ 18 hours/ha (for P3) = 373 hours/ha	
P4  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): - Legume Area (ha): - Yields: see above	Legume chosen: cowpea Reason: more profitable, less labour, the SOM is positive and hence not of first concern Area: a 1:1 rotation of 0.2025 ha of maize and Africa RISING cowpea each (total: 0.405 ha) Concerning maize: Yield: 800 kg/ha (traditional practice, see P1) +50% (P4) --> 1200 kg/ha Labour: 550 + 6.17 hours/ha = 556.2 hours/ha Use: all home consumed	When we revisited this household in August 2016 the female HHH stated that it was possible to add 0.405 ha for the 'implementation' of one (or several) of the AR packages.

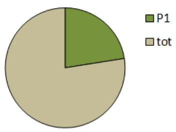
		Concerning cowpea: Yield: 580 kg/ha *0.875 = 507.5 kg/ha (580 kg/ha under P2 (3 sprays), now we reduce to 2 sprays, hence the 12.5% yield reduction as compared to P2) Labour: 150 hours/ha + 4.94 hours/ha (for P2) - 1.24 hour/ha per spray --> 153.7 hours/ha Use: all home consumed	
P5  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): - Legume Area (ha): - Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	Same as above.

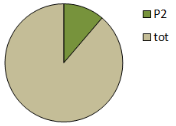
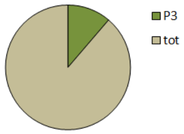
Farm #5: Medium Resource Endowed (MRE) household

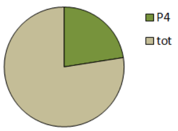
Context:

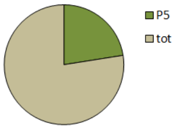


Area (ha)	Profit (GHS/yr)	Labour (hours/yr) household + hired	SOM (kg/ha)
1.2	3672	2241 + 0	-301

	Baseline	Assumptions	Farmer Feedback
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 0.27 Maize yield (kg/ha): 1423 Labour (h/ha): 763.4 Seed type: recycled Seed rate (kg/ha): 5 NPK (kg/ha): 185.2 SA (kg/ha): 93	This farm uses less NPK and SA than the 'traditional practice'. The farm however uses more fertilizer than the LRE and MRE farm in Duko (Northern Region), where we assumed a 150% yield increase. We hence assume a yield increase of 80%, which seems fair and in line with the previous assumptions. Area (ha): 0.27 Yield (kg/ha): +80 % --> 2561.4 kg/ha Use: 352 kg DM homer consumed Labour (h/ha): +2.47 hours/ha --> 765.9 hours/ha	When we revisited this household in August 2016 the HHH stated that he likes the idea of a higher fertilizer application (247 kg/ha of SA) but that it is too expensive for this HH. We still model P1 according to the recommended rates, To obtain a full technical evaluation.
P2	Cowpea Area (ha): 0.135	Area (ha): 0.135	-

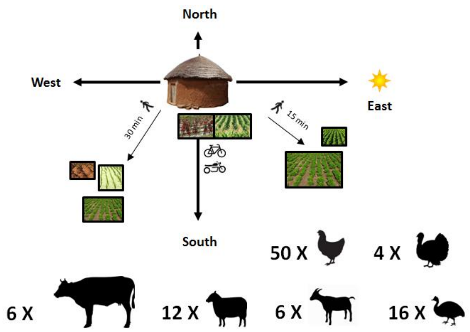
 *Areal extents (tot =remainder to total farm area)*	Cowpea yield (kg/ha): Labour (h/ha): 430.6 Seed type: improved Seed rate (kg/ha): 10 Sprays: 1	Instead of 1 spray, we assume 3 sprays now, we assume the use of the recommended seed rate (20kg/ha) = 133.2 GHS/ha of cultivation costs labour + 4.94 hours/ha --> 215.3 hours/ha yield: 430.6 kg/ha + 45% = new yield: 624.37 kg/ha	
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): 0 Soybean yield (kg/ha): - Labour (h/ha):- Seed type: - Seed rate (kg/ha): -	This HH so far does not grow soybeans. Since the HHH indicated that this HH does not have the financial means for an expansion of the farm area, we assume that soybeans must be grown on the areas of an existing crop. We chose to replace cowpea (legume for legume substitution). Note: The legume area (cowpea or soybean) is 0.135 ha. This is a very small piece of land: we assumed a greater piece of land (expansion) for the LRE household. This looks like a distortion (the MRE could probably grow more area with the legumes, but on the other hand: there seems to be no area available for the MRE HH while the LRE household uses such a small area that an expansion is easier (for her, the female LRE HHH, cultivating additional land is no problem from the perspective of 'buying/renting' the land, but from buying the inputs). Area (ha): 0.135 ha Yield (kg/ha): 825 kg/ha Since this household does not grow soybeans yet, we take a reference yield from other farmers visited (recorded yields range from 315 kg/ha - 662,4 kg/ha (average of 442kg/ha). Concerning the farmer reference yields it must be noted that this year the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). Since this is the reference yield and according to P3 the yields would increase by 50 %, we determine a yield of 825 kg/ha for the newly 'built in' Africa RISING soybean plot. Use: all home consumed Labour (h/ha): 709 h/ha +18 --> 727 hours/ha. Other farmers used on average 709 hours/ha for soybean (HH1, HH2 and	When revisiting the household in August 2016 the HHH stated that there is 'no market' for soybean so he is not interested in growing it.

		HH7). Hence this figure is assumed and we add 18 hours/ha (as defined in package 3) = 727 hours/ha.	
P4  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Legume chosen: cowpea Reason: more profit and less labour than soybean Background for cowpea (summary of changes): We assume a 12.5 % yield reduction from the 'actual/current' (3 sprays) due to the lower spray regime (2 sprays). The yield reduction is in line with the assumptions for the LRE farm for P4 (-12.5% likewise). Background for maize: We assume a +30% yield increase for higher (traditional practice) NPK and SA inputs first. We then assume the standard +50% yield increase for the rotation (maize after maize). The stepwise increase in yields leads to the highest assumed yield increase among all AR packages. By first increasing the baseline yield by 30% and THEN increasing the yield by 50% we are 'causing' a relatively high total yield increase. We could have seen the increases as 'a mere sum', assuming an overall increase of 80% as compared to the baseline. This would then correspond exactly to the assumptions in P1 (a further increase in fertilizers, as compared to the baseline). P4 however builds upon the 'traditional practice', so we decided to 'bring the production to the standard of traditional practice first' and THEN apply the 50% impact that refers to the rotation. We think that this assumption is the most realistic but we make our thoughts and steps transparent here, so anyone can change the assumptions according to their best knowledge. Area: 0.135 ha cowpea and 0.135 ha maize Concerning maize: Yield: 2774.85 kg/ha (this yield seems like a high figure, but compared to mother trial yields for the Upper East this one is very much in the normal range! So we assume that this yield is a suitable assumption for this scenario)	When we revisited this household in August 2016 the HHH confirmed that cowpea would be their choice for a rotation. The wife also confirmed this during a separate consultation. This HH already (currently) has a maize-cowpea rotation (AR), BUT: they do not apply the recommended fertilizer rates on maize. When we asked the HHH in August 2016 about the lower input rates he responded that he was not aware that he used less than the recommended rates. He thought he followed exactly what he was asked to do. We assume that now all the inputs are used according to the recommendations and that yields increase substantially. For simplicity we left maize and cowpea as separate fields in the model set-up.

		Labour: 763.4 hours/ha + 2 hours/ha (more fertilizer) = 765.4 hours/ha all HH labour, no hired labour Use: same as in P1 (a certain amount is home consumed, the remainder is sold) Concerning cowpea: 2 sprays Yield: 627.35 kg/ha * 0.875 = 548.9 kg/ha Labour: 215.3 hours/ha - 1.24 h/ha (2 sprays instead of 3) = 214.06 hours/ha all HH labour Use: all home consumed	
P5  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	-

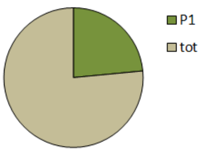
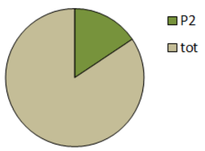
Farm #6: High Resource Endowed (HRE) household

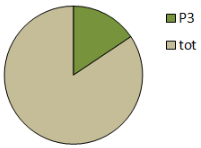
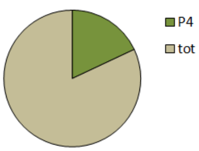
Context:

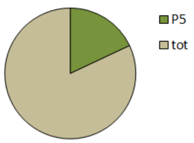


Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**

2.3	9442	1954 + 26	601

	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): 0.54 Maize yield (kg/ha): 943.7 kg/ha (compound) 808.8 kg/ha (former rotation) Labour (h/ha): 738.3 (compound) 612.3 + 30 hired (rot) Seed type: recycled Seed rate (kg/ha): 5 NPK (kg/ha): 185 SA (kg/ha): 123.5	Area (ha): 0.54 ha Yield (kg/ha): 'former rotation': 808.8 (+25%) --> 1010 kg/ha On the compound field the farmer currently applies less than the recommended amount of NPK/hectare, hence we have to assume that yield gains will be greater if both, NPK and SA, are increased (instead of just SA, in the standard assumption/reference scenario). For the MRE farm in Nyangua (UE) we assumed a yield increase of 80%, applying 123.5 kg/ha NPK and 61.75 kg/ha SA. The HRE farm applies 185 kg/ha of NPK and 123.5 kg/ha of SA + 5 donkey carts of organic manure; hence more fertilizer than the MRE HH in the same community. Therefore the yield increase (when applying 247 kg/ha NPK and 247 kg/ha of SA) will not be as big as 80%. We estimate a yield increase of 50% (as opposed to the standard 25% when shifting from the 'traditional practice' towards the Africa RISING recommended practice.) Yield on compound field: 943.7 *1.5 = 1415.6 kg/ha Use: all home consumed Labour (h/ha): + 2.47 hours/ha	When we revisited this household in August 2016 the HHH stated that the application of 247 kg/ha of NPK as well as the same amount of SA 'is good' but it is too expensive for this HH. We still decided to model the higher input rate and the associated benefits to make the ex-ante assessment of the proposed technology package.
P2  *Areal extents*	Cowpea Area (ha): 0.3589 Cowpea yield (kg/ha): 898 kg/ha on 0.207 ha (assumption! Actual crop failed!) and 45 kg/ha in a cowpea	Area (ha): 0.3589 Yield (kg/ha): + 45% --> 1302.1 kg/ha Assumed for all cowpea fields Use: 16.7 kg DM for home consumption; the cowpea grain that was intercropped with Sorghum: all home consumed	When we revisited this household in August 2016 the HHH stated that he would grow cowpea (in P2) as sole cowpea, not as an intercrop (as it is currently grown).

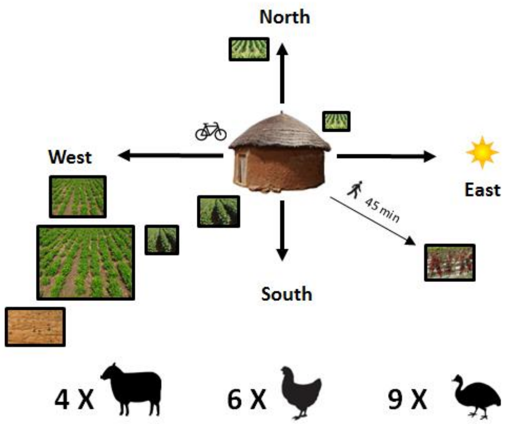
(tot =remainder to total farm area)	sorghum intercrop Labour (h/ha): 259 hours/ha for sole cowpea Seed type: improved Seed rate (kg/ha): 10 Sprays: 1	Labour (h/ha): +2.47 hours/ha + 1.24 per spray (*2) --> 281.28 hours/ha	
P3  *Areal extents* *(tot =remainder to total farm area)*	Soybean Area (ha): 0 Soybean yield (kg/ha): - Labour (h/ha):- Seed type: - Seed rate (kg/ha): -	We inserted a soybean area of equal size as the baseline cowpea area. Area (ha): 0.3589 ha Since this household does not grow soybeans yet, we take a reference yield from other farmers visited (recorded yields range from 315 kg/ha - 662,4 kg/ha (average of 442kg/ha). The mother trial yields range between 920 and 1240 kg/ha. Concerning the farmer reference yields it must be noted that this year the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). Since this is the reference yield and according to P3 the yields would increase by 50 %, we determine a yield of 825 kg/ha for the newly 'built in' Africa RISING soybean plot. #use: mainly home consumed Labour: 709 h/ha + 18 --> 727 hours/ha	We had first assumed that soybean would substitute cowpea. When revisiting the household in August 2016 the HHH stated that he would not replace cowpea but rather give soybean an extra area. We assume that the area is just as large as the cowpea field (just to 'build upon' the dimensions of existing land allocation) The HHH also stated that the household will consume the soybean and sell some (the excess).
P4  *Areal extents* *(tot =remainder to total farm area)*	Areas: see above Yields: see above	Legume chosen: cowpea Reason: more profitable, less labour, better SOM balance values We increased the labour of the Africa RISING cowpea rotation field but we left the cowpea (intercropped with sorghum) untouched (since it has completely different yields) and a different management).	When we revisited this household in August 2016 the HHH confirmed that cowpea would be the legume he would choose for a rotation (as well as the strip crop). The wife uttered the same opinion during a separate consultation.

		We hence had a cowpea area of 0.207 ha to rotate with maize. The Africa RISING maize rot area is 0.135 ha, hence 0.072 ha remained available for rotation with the maize grown on the compound field. We hence split up the compound field into two: a 0.072 part that is rotated with cowpea and the remaining part that stays exactly the same as in the baseline. Area: 0.207 ha for cowpea and maize each Concerning maize: Yield: +50% --> 1213.2 kg/ha Labour: +2.47 hours/ha --> 614.77 hours/ha household (regular) labour Use: all home consumed Concerning the legume: 1 spray Yield: 898 kg/ha (like baseline) Labour: +4.94 hours/ha --> 281.27 hours/ha (HH) Use: 90% sold , 10 % home consumed – like baseline	
P5  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	The HHH of this farm stated to prefer P5 over P4. Why? Planting is easier in a strip crop; the combination of crops (in P5) is more effective for the general plant growth. The strip crop is almost like a structured intercrop, with plants sharing space for their roots and leaves. With the plants sharing the leaves. At the field margins there is also a positive effect; the plant residues feed the land (green manure).

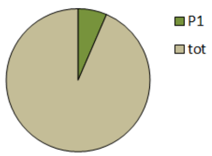
Upper West (UW) Region

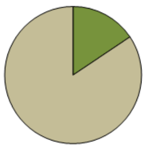
Farm #7: Low Resource Endowed (LRE) household

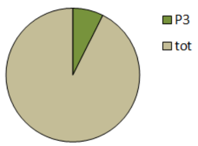
Context:

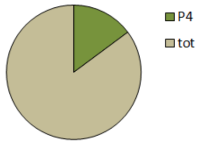
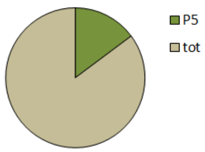


Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**
8.2	7959	1472 + 690	-236

	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize <u>Areas</u> (ha): total: 0.5289 ha Maize compound: 0.1013 ha Reset Africa RISING maize son: 0.3038 ha Reset Africa RISING maize Ego: 0.1013 ha Reset Africa RISING maize HHH: 0.0225 ha <u>Maize yields</u> (kg/ha): Maize compound: 960 kg/ha Reset Africa RISING maize son:	Area (ha): all maize fields Yield (kg/ha): + 25% for all 'reset' fields 150% for the compound field (like for the NR-MRE and LRE due to low or no fertilizer application in the baseline) --> 2400 kg/ha Use: all home consumed Labour (h/ha): +2.5 hours/ha	When we revisited this household in August 2016 the female HHH stated that she would be willing/interested to apply 2 NPK and 2 SA, but she could not afford it and she is lacking labour. Row planting is labour intensive and if she does not row plant then the subsequent labour steps (weeding, harvesting) are more labour intensive, too. She recycled Africa RISING seeds (does not buy improved seeds).

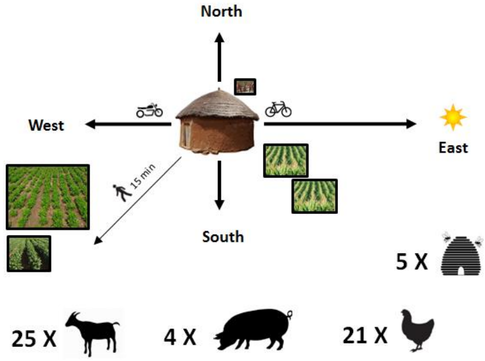
	1152 kg/ha Reset Africa RISING maize Ego: 864 kg/ha Reset Africa RISING maize HHH: 1610 kg/ha Labour (h/ha): Maize compound: 286.4+1.2 hired Reset Africa RISING maize son: 467.5 +2.5 hired Reset Africa RISING maize Ego: 1669.2 + 2.5 hired Reset Africa RISING maize HHH: 929 + 1.2 hired Seed type: recycled Seed rate (kg/ha): 5 NPK (kg/ha): 247 kg/ha on all fields except for compound (none) SA (kg/ha): 123 kg/ha on all fields except for compound (none)		
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Areas (ha): Total: 1.1588 ha FHHH: 0.405 Reset Africa RISING son: 0.0225 Son (own): 0.6075 Reset Africa RISING Ego: 0.1013 Reset Africa RISING HHH: 0.0225 Cowpea yield (kg/ha): FHHH: 66.1 Reset Africa RISING son: 336.6 Son (own): 232.2 Reset Africa RISING Ego: 201.1 Reset Africa RISING HHH: 908.52 Labour (h/ha): FHHH: 81.5 + 40 hired Reset Africa RISING son: 660.5 + 2.5 hired	Area (ha): all cowpea fields Yield (kg/ha): +45 % for all fields Use: all home consumed Labour (h/ha): + 5 hours/ha for all fields	When we revisited this household in August 2016 the household members stated that all farmers in this community spray 3 times on improved cowpea varieties. And yes, the household can implement the recommendations for P2 on all cowpea fields (even though they belong to different HH members). There is a labour constraint, especially for the female HHH (there are large differences in resources WITHIN this household).

	Son (own): 547 + 2.5 Reset Africa RISING Ego: 917.26 + 2.5 hired Reset Africa RISING HHH: 315 + 1.34 hired Seed type: improved Seed rate (kg/ha): 10 Sprays: 1		
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): 0 Soybean yield (kg/ha): - Labour (h/ha): - Seed type: - Seed rate (kg/ha): -	In order to model the impact of P3, we re-inserted the Africa RISING soybean trial field. Because it is such a small area, we assume that all the (non AR) cowpea area of the son is now also grown with soybean under P3. Area (ha): 0.6075 ha We take the actual/current soybean trial as a starting situation but we add the inputs (fertilizers): TSP: 60 kg/ha Inoculum: 0.247 kg # labour: household: 248.9 hours/ha + 18 hours/ha --> 266.9 hours/ha hired: 2.469 hours/ha # yield: + 50 % of the act/current yield 1297.8 kg/ha Use: all home consumed	When revisiting the household in August 2016 that if soybean was grown it would be consumed. Labour for threshing is difficult to get/expensive. The son actually/currently has an Africa RISING P3 Baby trial, but we reset it to zero in the baseline. We however have reference figures for yield and labour inputs through that. These are the references: The son has an Africa RISING soybean baby trial field (0.25 acres) = 0.10125 # yield: 865.2 kg/ha use: 100 % home consumed # cultivation cost: 37 kg/ha * 4.6 GHS --> 170.2 GHS/ha (Africa RISING standard assumed) The seeds were given to him, he does not know the variety not ploughed! = no contract work cost # labour: household: 248.9 hours/ha hired: 2.469 hours/ha inputs: no fertilizer!!
P4	Maize area (ha): Legume Area (ha): Yields: see above	Legume chosen: soybean Reason: more profitable, less labour, more SOM	When we revisited this household in August 2016 the household members stated that the maize cowpea rotation would be preferred. Since soybean

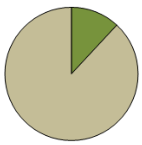
 *Areal extents (tot =remainder to total farm area)*		The soybean field has a size of 0.6075 ha, so all maize fields can be rotated with it, namely: - the compound maize field - the reset Africa RISING maize fields of the son, the FHHH and the daughter (Ego). Contrary to P3 we do not modify the soybean fertilization (we do not add TSP and Inoculum and the yields remain the same as in the actual/current situation). Area: 0.6075 ha for soybean and maize, each Concerning maize: Yield: +50% respectively Labour: +2.5 hours/ha respectively Use: all home consumed Concerning soybean: Yield: 865 kg/ha Labour: +1.24 hours/ha Use: all home consumed	performed better in FarmDESIGN (higher profit, less labour and higher SOM balance than for cowpea)
P5  *Areal extents (tot =remainder to total farm area)*	Maize area (ha): Legume Area (ha): Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	See above, same holds for the strip crop.

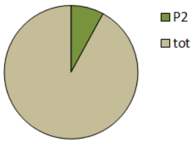
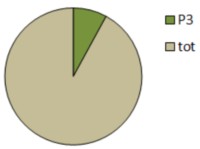
Farm #8: Medium Resource Endowed (MRE) household

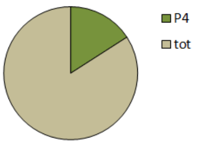
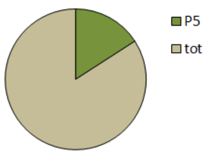
Context:



Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**
5.1	3041	1185 + 162	-317

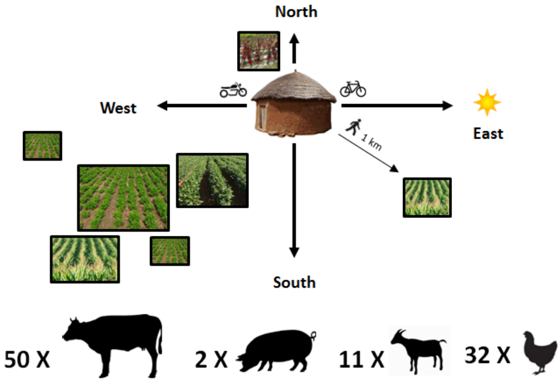
	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize Area (ha): total: 0.6075 Maize <u>yield</u> (kg/ha): Former rot: 1920 Wife: 654.55 Red maize: 480 <u>Labour</u> (h/ha): Former rot: 418.5 Wife: 712.3 + 88.9 hired Red maize: 158 Seed type: recycled Seed rate (kg/ha): 5	Area (ha): all maize fields Yield (kg/ha): +25 % respectively Use: all home consumed Labour (h/ha): +2.5 h/ha	When we revisited this household in August 2016 the HHH stated that he thinks 247 kg/ha of NPK and 123.5 kg/ha of Sa work best (instead of a higher SA dose). Mother trial data from the Upper West does not confirm this statement. Hence, we still model the effect of 247 kg/ha of each fertilizer, to have comparable assumptions among our case-study farm household. The HHH confirmed that all three maize fields could be cultivated according to P1. In the actual/current scenario, he already implemented a couple of Africa RISING like row planting and

	NPK (kg/ha): 247 SA (kg/ha): 123.5		burying the fertilizer instead of broadcasting it. The HHH feels that the method of 'burying fertilizer' requires more fertilizer than broadcasting.
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): 0.405 Cowpea yield (kg/ha): Wife: 295 General: 94 Labour (h/ha): Wife: 710 + 89 hired General: 119 + 200 hired Seed type: improved Seed rate (kg/ha): 10 Sprays: 1	Area (ha): the two cowpea fields --> 0.405 ha Yield (kg/ha): +45% Use: 29.2 kg DM home consumed (as in baseline); remainder sold Labour (h/ha): +5 h/ha	When we revisited this household in August 2016 the HHH confirmed our assumptions, but highlighting that so far he recycles the seed: this HH does not purchase improved seeds on the market (but recycles the improved seeds that Africa RISING gave to them)
P3  *Areal extents (tot =remainder to total farm area)*	Soybean Area (ha): 0 Soybean yield (kg/ha): - Labour (h/ha):- Seed type: - Seed rate (kg/ha): -	Area (ha): 0.405 ha In order to model the impact of P3, we added a soybean field (of 0.405 ha) Since this household does not grow soybeans yet, we take a reference yield from other farmers visited: recorded yields range from 315 kg/ha - 662,4 kg/ha (average of 442kg/ha). The mother trial yields (years 2013-2015) are 2487 kg/ha on average, which seem unattainable when comparing it with farmer yields. It must be noted that this year the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). Since this is the reference yield and according to P3 the yields would increase by 50 %, we determine a yield of 825 kg/ha for the Africa RISING soybean plot. note: farm #7 (LRE household in same community) achieves	When revisiting the household in August 2016 the HHH stated that IF he would grow soybean he would do so on an additional piece of land instead of substituting an existing crop *e.g.* cowpea. We assume an equally large area than the cowpea, to stay within realistic proportions in our assumptions.

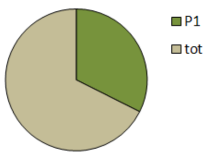
		1470 kg/ha of soybean under P3. Given the much lower yield of cowpea in the HRE and MRE farm as compared to the LRE farm we still assume the average soybean yield + 60 % = 825 kg/ha. It is assumed that soybean grains mainly will be sold (90% of the yields). Other farmers used on average 709 hours/ha for soybean (HH1, HH2 and HH7). Hence this figure is assumed and we add +18 hours/ha (as defined in package 3) = 727 hours/ha.	
P4  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Legume chosen: soybean Reason: higher profits, more SOM (slightly higher labour) In order to model P4 we assumed a maize soybean rotation. Soybean is assumed to be cultivated on an area of 0.405 ha. Hence also only 0.405 ha of maize can be rotated with the soybean. We chose that the AR maize (groundnut rot) and the Africa RISING maize (wife) shall be rotated with the soybean. The 'red maize'-field is not rotated (it is more traditional and the household has shown experimentation with the two other fields, but not with this one). Hence all maize fields except the 'red maize' receive yields of + 50%, but labour increases by +2.47 hours/ha. For soybean: yield is 550 kg/ha for soybean, no fertilizer and no extra labour, except for +1.24 hours/ha extra for the rotation.	When we revisited this household in August 2016 the HHH stated that he would rather grow soybean than cowpea, if he was not provided with the inputs for soybean by Africa RISING. Since soybean also performed better in FarmDESIGN (higher profit, less labour and higher SOM balance than for cowpea) we chose soybean for P4 and P5.
P5  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	See notes above.

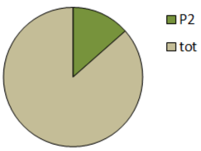
Farm #9: High Resource Endowed (HRE) household

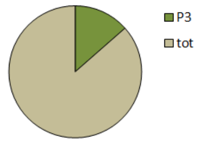
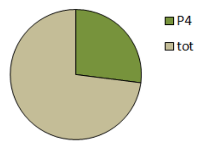
Context:

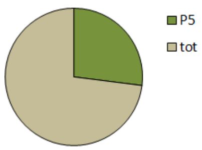


Area (ha)	**Profit (GHS/yr)**	**Labour (hours/yr) household + hired**	**SOM (kg/ha)**
7.5	15292	4414	162

	Baseline	**Assumptions**	**Farmer Feedback**
P1  *Areal extents (tot =remainder to total farm area)*	Maize <u>Area</u> (ha): Total: 2.43 Compound: 0.6075 Maize (+Roselle): 0.81 Field (Strip): 0.81 Field (HHH): 0.2025 Maize <u>yield</u> (kg/ha): Compound: 960 Maize (+Roselle): 720	Area (ha): 2.43 Yield (kg/ha): +25 % respectively Use: 100% home consumption according to the actual/current situation Labour (h/ha): +2.5 hours/ha respectively	When we revisited this household in August 2016 the HHH confirmed that indeed, all four maize fields could be transformed into 'Africa RISING P1 fields'. The HHH confirmed that 247 kg/ha NPK and SA respectively is the best options. This is confirmed by trials and matches our model assumptions.

	Field (Strip): 720 Field (HHH): 540 <u>Labour</u> (h/ha): Compound: 694.6 +2.5 hired Maize (+Roselle): 421 +2.5 hired Field (Strip): 515 + 2.5 hired Field (HHH): 359 + 118.5 hired Seed type: recycled Seed rate (kg/ha): 5 NPK (kg/ha): 247 SA (kg/ha): 123.5		
P2  *Areal extents (tot =remainder to total farm area)*	Cowpea Area (ha): total: 1.0125 Compound: 0.2025 Field 1: 0.81 Cowpea yield (kg/ha): Compound: 375.3 Field 1: 94 Labour (h/ha): Compound: 1173 Field 1: 256 Seed type: improved Seed rate (kg/ha): 10 Sprays: 1	Area (ha): all two cowpea fields Yield (kg/ha): + 45 % respectively Use: all home consumed Labour (h/ha): +5 h/ha respectively 3 sprays	When we revisited this household in August 2016 the HHH confirmed that all of their fields could be 'converted' to P2 and that 3 sprays 'work best' in his opinion. The wife was of the same opinion.
P3	Soybean Area (ha): 0 Soybean yield (kg/ha): -	In order to model the impact of P3, we inserted the soybean field on the area of the cowpea fields (substituting cowpea):	When revisiting the household in August 2016 the HHH stated that if soybeans were grown this HH would

 *Areal extents (tot =remainder to total farm area)*	Labour (h/ha):- Seed type: - Seed rate (kg/ha): -	Since this household does not grow soybeans yet, we take a reference yield from other farmers visited: recorded yields range from 315 kg/ha - 662,4 kg/ha (average of 442kg/ha). The mother trial yields (years 2013-2015) are 2487 kg/ha on average, which seem unattainable when comparing it with farmer yields. It must be noted that this year the yield was very low due to unfavourable weather conditions, hence the average reference yield can slightly be adjusted upwards (suggestions: 550 kg/ha). Since this is the reference yield and according to P3 the yields would increase by 50 %, we determine a yield of 825 kg/ha for the Africa RISING soybean plot. note: farm #7 (LRE household in same community) achieves 1470 kg/ha of soybean under P3. Given the much lower yield of cowpea in the HRE farm we still assume the average soybean yield + 50 % = 825 kg/ha. Area (ha): 1.0125 ha Other farmers used on average 709 hours/ha for soybean (HH1, HH2 and HH7). Hence this figure is assumed and we add +18 hours/ha (as defined in package 3) = 727 hours/ha.	mainly use it for home consumption.
P4  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Legume chosen: Soybean Reason: higher profits, more SOM (slightly higher labour) Area: 1.0125 ha for soybean and maize each In order to model P4 we adjusted P3 (550 kg/ha for soybean, no fertilizer and no extra labour, except for 1.24 hours extra for the rotation) two maize fields receive yields of + 50%, but labour increases by +2.47 hours/ha, namely: the maize on field 3 (HHH) and the maize field 3 (strip), since the soybean as well as these maize are grown on the fields of the HHH and this way the maize and the soybean areas are exactly the same (0.10125 ha). The remaining maize areas remain as in the baseline.	When we revisited this household in August 2016 the HHH stated that he is not in favour of growing soybean since it failed in the past. IF this household would grow soybean then they would keep it for home consumption. The residues would be sued as green manure. To put its labour demand into proportion: Yam needs most labour, soybean needs more labour than maize and cowpea needs less labour

			than maize. Since soybean performed better in FarmDESIGN (higher profit, less labour and higher SOM balance than for cowpea)
P5  *Areal extents (tot =remainder to total farm area)*	Areas: see above Yields: see above	Same as above, except for higher labour requirements as described in Table 2 of the article.	See above.

Annex 4E

FarmDESIGN model. Zip file. Accessible online at: https://doi.org/10.1016/j.agsy.2018.01.028

Annex 5

Annex 5 includes

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5H.Results. Main reasons for minimum and maximum values of flexibility ranges
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5A. Methods. Case-study site

The study was conducted in Duko (9.56° N -0.83° W), a Dagomba farm community located 18 km North of Tamale, the capital of Ghana's Northern Region (NR). Figure A5.1 displays the NR and the case-study location. Duko is part of the Guinea Savannah agro-ecology, evincing a unimodal rainfall regime with 1000-1200 mm of rainfall per year. Temperatures range between 26 and 30°C. Duko hosts a total of 54 smallholder farm households. Most households are male headed (NR average: 92.2% (GARBES, 2014)), large, with on average 12 members, and polygamous, adhering to Muslim religion. Local smallholders grow cereals (maize, rice, millet), tubers (yam, cassava, sweet potato), legumes (cowpea, soybean, groundnut, bambara bean) and dry season vegetables (tomato, okro, chili pepper, green leafy vegetables). Depending on their resource endowment, farmers may also own cattle, donkeys, small ruminants and poultry. The higher a households resource endowment the larger the proportion of land allocated to cash crops, the stronger the market-orientation (Kuivanen et al., 2016b), the more likely the ownership of more (expensive) animals and the greater the room to manoeuvre (Michalscheck et al., 2018a). Within households, men are responsible for the purchase of agricultural inputs (seeds, chemicals) as well as livestock sales (Iddrisu Baba Mohammed, 2016: *pers. comm.*) while women in Duko usually manage the crop sales as well as the purchase of non-staple-food for home consumption. Many women in Duko describe themselves as traders rather than farmers, often purchasing produce *e.g.* unshelled rice, to process and sell it at a higher price. In Duko it is common for the wives and the oldest sons to cultivate individual fields (Apusigah, 2009). Cultivating an individual field implies asking the household head (HHH) for seasonal permission of use. If permission is granted, the individual household member gains autonomy concerning the crop choice for his or her own field, but in terms of household labour allocation, the HHHs fields remain the priority. The HHHs fields feed the family and all household members, as far as present and able, are expected to support the cultivation with their labour force, their expertise and money for inputs.

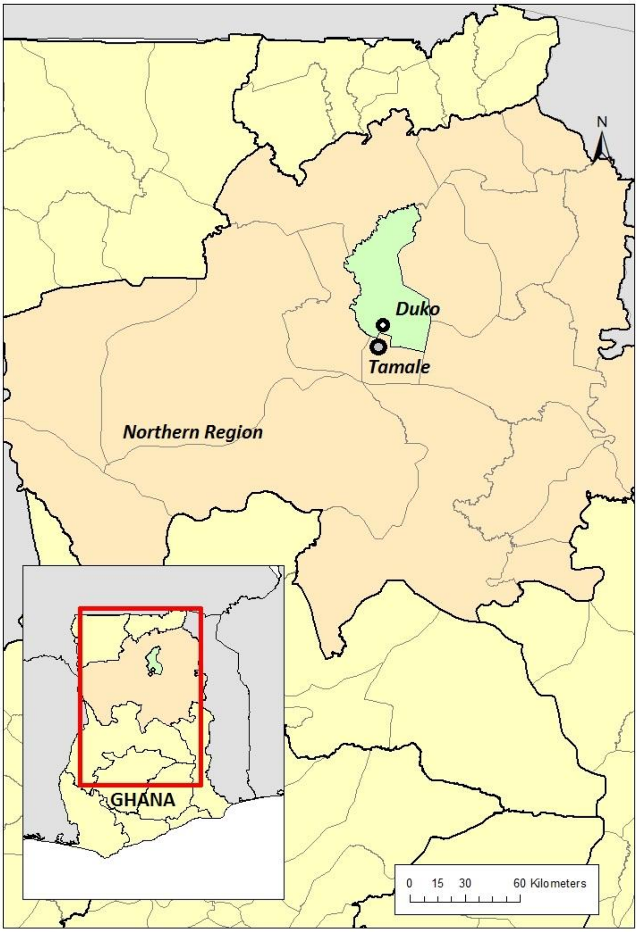


Figure A5.1. *Map of Northern Ghana, showing Duko in the Savelugu-Nanton district (green area) and Tamale, the capital of the Northern Region (red area).*

Short video impressions of Duko are available online at: https://www.dropbox.com/s/jfd9dtoowlnj8w1/Duko%20movie%20short.mp4?dl=0

You may also access the video via the QR-code, using a mobile device:

5B. Methods. Decision theory and physics

The fundamental concept in social science is power, in the same sense in which energy is the fundamental concept in physics. (Russell, 1938)

In order to analyse intra-household decision-making, we employed concepts of economics, socio-psychology and physics. Economics provided us with the decision theory to describe and compare individual interests. Socio-psychology offered an operational definition of social power and Newtonian physics enabled us to visualize how the interplay of different interests and power positions may result into decisions on land allocation at farm-household-level.

Interests

Classic decision theory holds that a person's decision, when confronted with various choices, depends on his or her subjective expected utility *i.e.* on the likelihood as well as the benefits associated to a particular choice by a particular person (Pollard and Mitchell, 1972). While the decision on land allocation is a joint one at household level, the perceived utility is personal. In order to determine individual interests, we decouple utility from the probability associated to a choice (crop area), enquiring about the desirability of each option as if it was equally likely: 'Imagine the crop area of maize/cowpea/soybean was x acres. How satisfied would you be?'. By equating utility with the respondents' self-reported level of satisfaction we consciously leave it to each individual respondent to consider and value aspects defining his or her satisfaction (Berg and de Jong, 2002).

The levels of satisfaction, ranging from 0% (not satisfied) to 100% (fully satisfied), towards different (technically possible) decision-outcomes (crop areas) were used to create utility curves (Fig. A5.2). The utility curves are firstly defined by physical boundaries *i.e.* the total farm land available to the household. The individual utility curves per crop are furthermore limited by minimum and maximum acceptable values, at which the utility drops to zero.

By comparing the individual curves at household level, we identify differences or trade-offs in satisfaction for each land allocation option. The term trade-off expresses the impairment of interests of at least one household member resulting from a decision taken to the benefit of at least one other household member. Aggregating the individual satisfaction-levels reveals the household-level utility per land allocation option. We test whether the household-utility is highest at the actual crop area (Bourguignon et al., 2009).

We analyse and compare the shape and width of the utility curves. The width of a curve reveals the 'room to negotiate': a wide curve indicates agreement with a wide range of options (Figure A5.2b), while a narrow curve suggests little flexibility *i.e.* little room for negotiation (Figure A5.2c). Concerning the shape, we classify the curvatures between the minimum and the ideal (min-ideal) as well as the ideal and the maximum (ideal-max) as linear, convex (downwards), concave (downwards), as cut-off (impossible or inflexible). An impossible cut-off denotes a situation where the ideal equals zero, implying the impossibility of a decrease. When the minimum or the maximum equal the ideal we refer to an inflexible cut-off, indicating that the respondent was not willing to decrease or increase the area. The shapes were visually determined.

While utility functions serve to analyse interests and satisfaction, the likelihood of a land allocation option may be determined when including the power dimension.

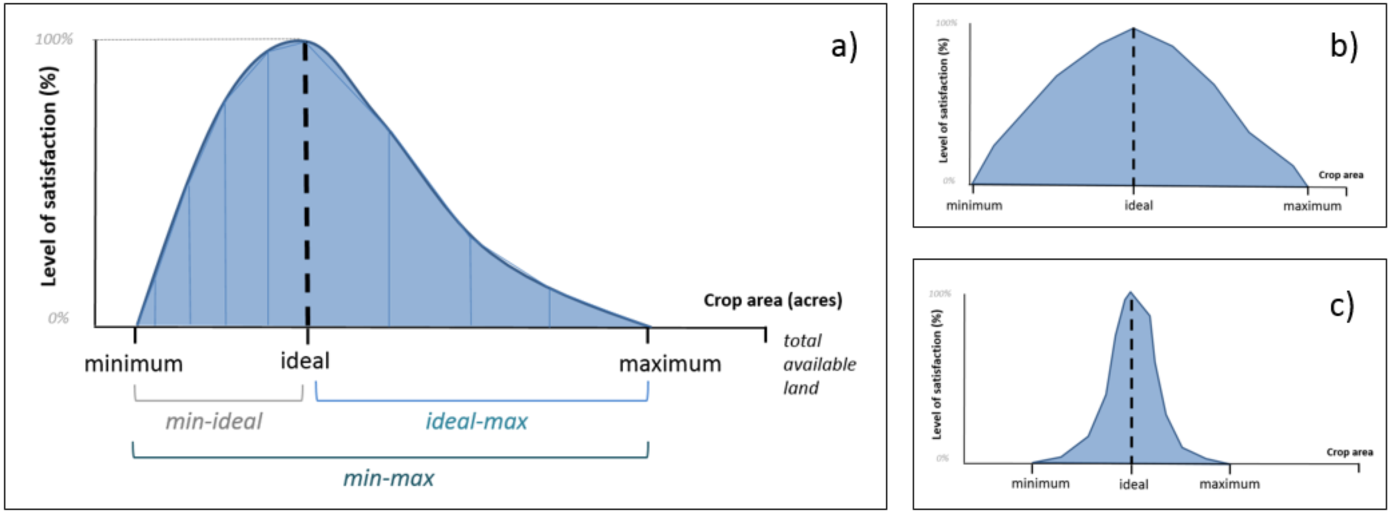


Figure A5.2a*) Exemplary utility curve with flexibility ranges. Crop area (acres) and level of satisfaction (0-100%) are plotted on the x- and y-axis respectively. The distances from the minimum to the ideal (min-ideal), the ideal to the maximum (ideal-max) as well as the minimum to the maximum (min-max) are interpreted as flexibility ranges. A5.2b) and A5.2c) display a wide and a narrow utility curve respectively.*

Power

In the context of our study, the term power is understood as 'behavioural social power', which is the ability of person A to get person B to do something that B would not otherwise do (Dahl, 1957). Rucker and Galinsky (2017) provide a more complex definition, describing its application as optional and its existence as independent of a successful exertion. According to Dahl (1957) a full analysis of social power includes information about the base (source, domain), the means (executive instruments) and the amount (extent, relative share) of power. Taking the example of a smallholder household in Duko: the fact that a HHH owns the land (power base) may allow him to threaten reluctant household members with the withdrawal of their individual parcels (power means), leading to an absolute (100%) compliance with his will (indicator: amount of power). In this paper we focus on the amount of power, since it directly determines the outcome of a negotiation process. In negotiations, power is measured best in cases of disagreement (Dahl, 1957; Pollard and Mitchell, 1972), since it is here that the assertiveness of the different actors shows. The accuracy of predictive models hence must be determined by their performance in cases of disagreement. In line with Dahl (1957) and Anderson (2017), we express the amount of power per household member *i* as his or her relative power share P_i.

5C. Methods. Household survey (direct scoring approach)

The aim of the household survey was to capture the interests (satisfaction) and power positions of the different household members concerning land allocation to maize, cowpea and soybean. Between April and June 2017, we interviewed 58 members of 18 households. The household survey template as well as a video documentation on how each survey section was applied are available through the links below.

Table A5.1. Household Survey Sections

Section	Content	Link to video impression	QR-codes for quick access to videos using a mobile device
Page 1	Household information: location, resource endowment	https://youtu.be/SmIJzCiT2gc	
Page 2	Household members, basic descriptions of decision-making processes	https://youtu.be/DOcyDBObPyk	
Page 3	Joint mapping exercise	https://youtu.be/ZXdr8Hi2z7w	
Page 4	Congruence scores (not part of the analysis in this paper)	https://youtu.be/zLX0mIsPrD0	
Page 5	Levels of Satisfaction	https://youtu.be/9g4px9DO4CA	
Page 6	Interest, power and satisfaction	https://youtu.be/fcsynnC3iFQ	
Survey template	Final version of the survey template (incl. parts for sensitivity analysis)	https://www.dropbox.com/s/htytk9ymrlbv325/Template.xlsx?dl=0	

The survey was split into two parts: a shared one, involving two or more adult household members, and a subsequent individual part, for confidential consultations with particular household members. All survey questions referred to the previous main cropping season, *i.e.* May to November 2016. Concerning individual interests, respondents were asked to remember the situation before the household met to decide on land allocation. For the respondents to reminisce about the relevant point in time, we primed them, asking about the weather (late start of rains) and the household situation in April to May 2016.

The shared part of the survey recorded farm features and household composition. It also contained a joint mapping exercise to capture the previous season's actual land allocation to the different crops. The joint nature of the mapping exercise created a shared reference point on land resources and land allocation, a necessarily uniform information for the ensuing, individual consultations.

While the joint mapping exercise was fundamental in establishing a joint reference base, powerful household members may have dominated an over- or underreporting of crop areas that was not openly disputable by less powerful household members. As far as possible, we tried to encourage and safely engage every participant to contribute his or her personal best knowledge to the exercise. We, however, decided to accept the remaining risk of this bias, since a joint reference was indispensable.

In the individual consultations, we only referred to the household (head's) fields, not to fields whose seasonal use was granted to a particular individual, since as such, individual fields have turned into a private good, temporarily withdrawn from the household domain.

The individual consultations included two steps.

1) An exercise to determine the level of satisfaction associated to different crop areas for maize, cowpea and soybean.

2) A direct assessment of interest in participation, the actual influence on and the satisfaction with decisions on land allocation.

Step 1) Levels of satisfaction (utility)

We asked each respondent individually about the level of satisfaction associated to different crop areas of maize, cowpea and soybean for the cropping season of 2016. Each respondent was hence asked to think of the household's needs as well as its resources in April to May 2016. We then asked, under these conditions, 'if it was entirely up to you, how much of the total farm land would you have ideally (*i.e.* 100% satisfaction) allocated to maize, cowpea and soybean respectively?'. We then enquired about the acceptable minimum and maximum area per crop and reasons for not accepting a smaller or larger area. We assumed that below or beyond the minimum and maximum crop area, satisfaction was equal to zero, not determining possibly negative satisfaction levels or resistance. The minimum and maximum served as boundaries for the utility curves. We then consulted the respondent on how fast or slow their satisfaction was lost when moving away from the ideal towards their upper and their lower limit.

Figure A5.3. *Photo impression of scoring exercise, assessing the levels of satisfaction.*

Similar to the Pebble Distribution Method (Shiel et al., 2003), we provided farmers with wooden sticks to express (score) their personal level of satisfaction, with ten sticks equating full (100%) satisfaction and zero sticks no (0%) satisfaction. We drew the maximum area into the sand, demarcated the ideal and the minimum areas and divided the intermediate areas into four to six equal steps (*cf.* Fig. A5.3). Step-wise changes, as opposed to smooth increases or decreases, facilitated the respondents' perception of changes in satisfaction (Gilboa, 2008). For each step we asked about the respondent's level of satisfaction, which the respondent expressed through the number of remaining sticks.

A detailed description as well as video impressions on how we interacted with farmers to record the rather abstract levels of satisfaction, can be seen in the video-tutorial for survey page five as well as here:

For Duko (*language: Dagbani, English subtitles*): https://www.dropbox.com/s/p3bo0ee00up3p0f/ITTAGh.mpeg?dl=0

You may also access the video via the QR-code, using a mobile device:

Another example from the same type of work in Upper East; Nyangua *(language: Kassim, English subtitles)*: https://www.dropbox.com/s/01w60y6o5v3d1ai/Video%20with%20Subtitlesshort.mp4?dl=0

You may also access the video via the QR-code, using a mobile device:

We call our method the stick-score method, characterized by the use of ten sticks that serve to visualize abstract concepts like satisfaction, power and the level of interest.

Step 2) Interest, Power and Satisfaction

The second part of the survey consisted of direct inquiries about the respondent's interest to participate in decisions on land allocation, his or her assessment of the intra-household power distribution and the level of satisfaction with decisions made. We used the stick-score method, with zero sticks expressing no- and ten sticks expressing a high level of interest or satisfaction. To assess the power distribution, we asked the respondents to fictively apportion the ten wooden sticks to powerful household members, so that the relative distribution of sticks would reflect the power shares per person (P_i) within their household. We enquired whether the power domains were crop-specific *i.e.* whether different household members had different power shares per crop. A crop-specificity in power distribution was not confirmed by respondents, hence our results on power are not crop-specific either. During the data analysis, we inferred the actual power structure by triangulating all individual statements on power distribution as well as household-specific, qualitative anecdotes.

We used SPSS Statistics (version 22) to examine the data on interests and power positions for patterns according to gender (sex and age) and household resource endowment using the Spearman's rank-order correlation coefficient for numerical- and the association- and effect-size measures Eta (η) and Eta squared (η^2) for nominal variables. In this paper we present the main, significant results of our analyses.

The household survey data can be downloaded at:

https://www.dropbox.com/s/4mk650xa5o14h62/Household%20Survey%20Data.7z?dl=0

You may also access the data via the QR-code, using a mobile device:

5D. Methods. Decision models

5D1: The Generic decision rule

The Dagomba cultural norm, as for most tribes in Northern Ghana, holds that the male HHH owns and allocates the land. The HHH may allocate the land to crops of his choice or to other household members, as individual fields. The generic decision rule hence assumes that the ideal area (IA) of the HHH indicates the AA.

5D2: The Utility-power model

The utility-power model extends the utility curves by the power dimension. The model calculates the predicted area (*PA)* as the land allocation option (crop area between the minimum and maximum acceptable area) with the largest power-weighted utility (*PWU*) at household level. We first determine the individual PWU_a values per option *a* by multiplying the individual satisfaction ($S_{a,i}$) level with the individual power shares (P_i). Subsequently we sum up the weighted values of all respondents to delineate the overall interest and power ‘backing’ per land allocation option at household level (Equation (1)). PA is the maximum PWU_a value.

$$PWU_a = \sum_i^n S_{a,i} * P_i \qquad (1)$$

5D3: The Newtonian model

For the third model we hypothesize that the complex interplay of interests and power positions within households may be represented by vectors like in a parallelogram of forces in Newtonian physics. We thereby assume that, despite the existence of a range of acceptable land allocation options, in a negotiation, each household member will take stand for one option only (Kubanek, 2017), namely his or her ideal area (IA). The vector direction indicates the interest (represented by the IA) of a person while the length (magnitude) represents the individual 'social power share' (P_i), *cf.* Figure A5.4.

The individual vectors (here: A, B) add up to a resulting vector (here: C), indicating the PA. We furthermore assume that, in case of the PA being a fraction number, the AA rather corresponds to a nearby integer than to the mathematically precise amount. By allowing a deviation of up to 10% between the PA and the AA, we test whether the Newtonian model correctly predicts the 'decision direction'.

Consider a household consisting of *n* adult members represented by the set I = {A, B,., n}. P_i is the power share (fraction) held by household member *i* and P_{res} the resultant power (Equation (2)), defining the magnitude of vector $\vec{C}$. Each powerful member is hence represented by a vector, influencing the final decision-outcome C. Equations (3) and (4) serve to determine the angle of vector $\vec{C}$ and the resulting area C respectively. *T* denotes the total available farm land of the corresponding household.

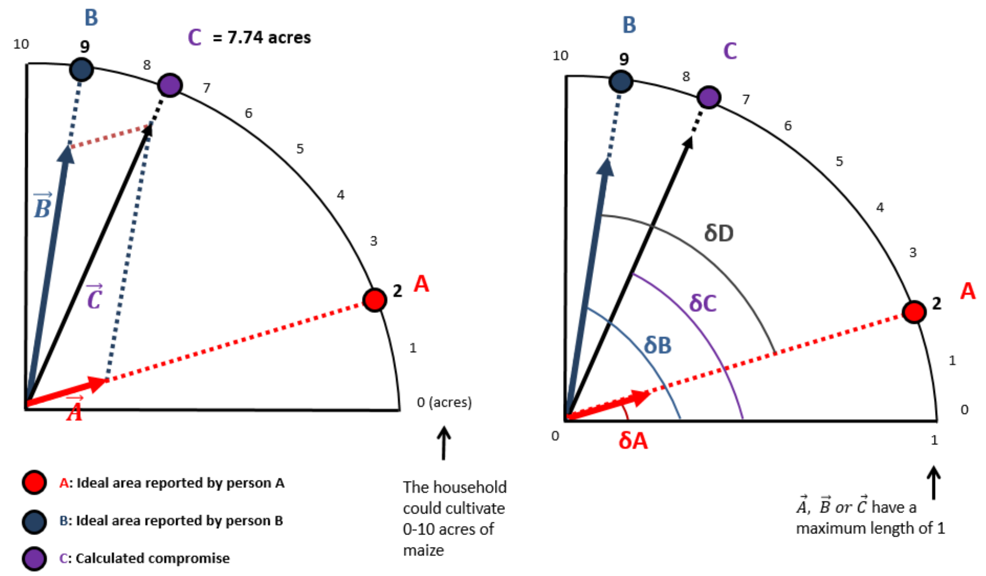


Figure A5.4. *Parallelogram of forces, visualizing the interplay of interests and power positions within a household. Example: land allocation (acres) to maize; two actors (persons A and B) have distinct interests and different power positions, hypothetically leading to a compromise (C=PA). The circular sphere indicates possible crop areas. Its distance from the origin is defined by the maximal length (unitary total power amount=1) of the individual vectors or of the resulting vector* $\vec{C}$.

$$P_{res} = \sqrt{(P_A \cos \delta A + \cdots + P_n \cos \delta N)^2 + (P_A \sin \delta A + \cdots + P_n \sin \delta N)^2} \quad (2)$$

$$\delta C_{res} = \tan^{-1} \frac{P_A \sin \delta A + \cdots + P_n \sin \delta N}{P_A \cos \delta A + \cdots + P_n \cos \delta N} \quad (3)$$

$$C = \frac{\delta C_{res}}{90°} * T \quad (4)$$

5E. Methods. Utility levels and alternative farm configurations

Michalscheck et al. (2018a) employed the whole-farm model FarmDESIGN to explore alternative farm configurations for three smallholder farm systems in Duko. The explorations assumed technically possible rooms to manoeuvre for changes in the maize, cowpea and soybean crop areas (*cf.* Annex 4: Model assumptions per farm (FarmDESIGN)). We chose the medium resource endowed farm, as described in Michalscheck et al., to exemplify the applicability of utility levels to model-determined farm configurations. Utility levels and the baseline farm configuration for FarmDESIGN were assessed for the same year, avoiding mismatches based on inter-annual changes. While Michalscheck et al. compared the model-based impact assessment with farmer realities of individual technology packages, our analysis constitutes a social extension to the model-based exploration.

The FarmDESIGN model

FarmDESIGN is a bio-economic, static model, extended by a multi-objective optimization algorithm (Groot et al., 2012). The optimization algorithm generates a large array of Pareto-optimal alternatives to the current farm configuration *i.e.* it allows an exploration of technical possibilities to re-arrange the farm resources. Michalscheck et al. explored relations among three farm objectives, namely profit maximization (GHS/yr), maximization of the soil organic matter (SOM) balance (kg/ha/yr) and minimization of the labour balance (hours/yr). In their study, Michalscheck et al. tested the impact of five technology packages proposed by a local Research for Development (R4D) project. The technology packages implied augmented input levels for maize, cowpea and soybean or a maize-legume integration in the form of a rotation or a strip crop. The packages were available to the model during the exploration, increasing the options for farm re-configuration as compared to the baseline. FarmDESIGN would then adopt the technology packages or maintain the current practice in order to fulfil the farm objectives. To a defined extent, the model was able to alter the total farm size and the size of household fields, feed imports and crop residue allocation. Sizes of individual fields, *e.g.* that of the wife, son or daughter, were fixed (variation < 5%) in order to respect these as the actual results of a negotiation within the household. Allowing the removal, reduction or increase of individual fields would have neglected existing social structures and translated into socially inacceptable farm configurations. After setting decision variables, constraints and objectives, an exploration was run at 1000 iterations, generating solution clouds of alternative farm configurations. The term 'solution cloud' derives from the graphical representation of the alternative farm configurations in scatterplots, revealing the performance of each configuration in terms of the three farm objectives.

Matching model results with utility levels

We use the same scatter plots as presented in Michalscheck et al., with two out the three farm objectives (operating profit, the SOM and labour balance) on the axes, respectively. In order to visualize the degree of satisfaction of a particular household member towards each model-proposed alternative farm configuration, we assign a colour code to the dots of the solution clouds, expressing the different levels of satisfaction, *cf.* Table A5.2.

Table A5.2. *Colour code, indicating level of satisfaction*

Satisfaction (%)	**0**	**1-9**	**10-19**	**20-29**	**30-39**	**40-49**	**50-59**	**60-69**	**70-79**	**80-89**	**90-99**	**100**
Colour												

Figure A5.5. *Individual utility of model-generated alternative farm configurations for one medium-resource endowed smallholder farm household in Duko. The colour scale expresses the level of satisfaction (0-100%) associated with the respective crop area per household member.*

Figure A5.5 did not reveal any gradient according to optimization objective, hence we illustrated the results in bar charts with average utility levels per crop, *cf.* Figure 5.4 in the manuscript.

The data underlying the analysis and the graphics can be accessed online at:
https://www.dropbox.com/s/crxny6cbq6xzz3l/SolutionCloud_Utilities.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

5F. Results. Gender, power and resource endowment (detailed results)

Among the 58 respondents we counted 18 male HHHs, 25 wives, 11 sons, one daughter, two brothers and one parent of a HHH. In 15 out of 18 households, the HHH held the bulk of the power, sharing it mainly with his son(s) and, to a limited extent, with his wife or wives. Sex was found to be highly associated with power share ($\eta^{2=}$0.506), with men being more likely to hold more power than women.

Among men, the power share was found to be positively correlated (r_s=0.587; p<0.01) with age, while no significant correlation was found between the age of women and their power share. The power distribution varied, amongst others, according to resource endowment as expressed by the household size (implying labour force), total farm land and livestock ownership, *cf.* Figure A5.6.

A Spearman's rank-order correlation revealed that the power of the HHH was negatively correlated with the total farm land (r_s=-0.596; p<0.01), increasing livestock ownership (r_s=-0.495; p<0.05), household size (r_s=-0.569; p<0.01) and power share of the son(s) (r_s=-0.642; p<0.01). The power of the son(s), however, was positively correlated with livestock ownership (r_s=0.556; p<0.05), farm land (r_s=0.651; p<.01) and household size (r_s=0.507; p<0.01). With increasing power, sons are also able to cultivate more individual land (r_s=0.494; p<0.05). The power of the wife was negatively correlated to the power of the son (r_s=-0.557; p<.05), indicating that in many cases her power share depended on the presence of an adult son.

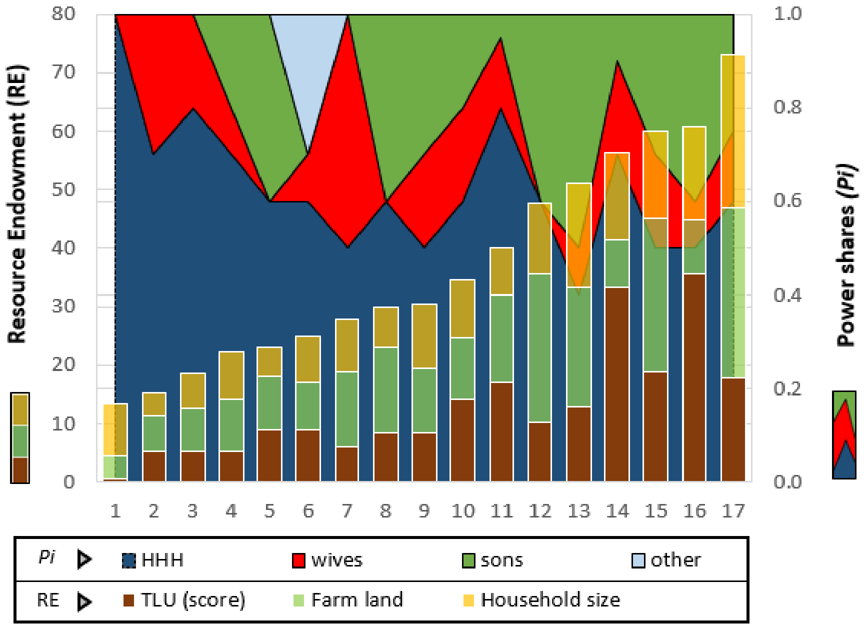


Figure A5.6. *Resource endowment (RE) scores and power distribution (Pi). The RE score is composed of livestock ownership, measured as Tropical Livestock Units (TLUs), the total farm land (acres) and household size (number of members). The results per household are sorted according to an increasing RE score, displayed by resource endowment ranks 1-17. The results of the 18th household with the highest endowment (RE score: 390) were omitted, since they prevented differentiability among the remaining cases.*

The amount of individual land was significantly correlated to livestock ownership (r_s=0.637; p<0.01), land (r_s=0.716; p<0.01) and household size (r_s=0.644; p<0.01) *i.e.* the higher the household resource endowment the greater the amount of land allocated to individual household members. The total land area of a household was significantly correlated with the age of its household members, with a higher average age implying a greater total farm land (r_s=0.425; p<0.01).

Concerning the ideal crop areas (IAs) of the different household members and the frequency of discord, we found disagreements in 74% (40/54) of the cases, mostly (29/40) between the wives and the HHH. In 37% (10/27) and 56% (5/9) of the cases there was a discord between a son or another household member (brother, parent), respectively. When comparing the reported IAs per crop among household members, we found that both, wives and sons, were interested in larger cowpea and soybean areas and in smaller maize areas than the HHHs, *cf.* Figure A5.7.

We furthermore found that the greater the power share (r_s=0.658; p<0.01) or the age (r_s=0.491; p<0.05) of a respondent the greater the reported IA for cowpea. We also checked whether the release of individual fields lead to greater consent and commitment to land allocation at household level. We did not find a significant correlation between the amount of individual land and the respondents (dis)similarity of interests at household level. The household level divergence in interests was, neither, significantly correlated to resource endowment nor to crop type.

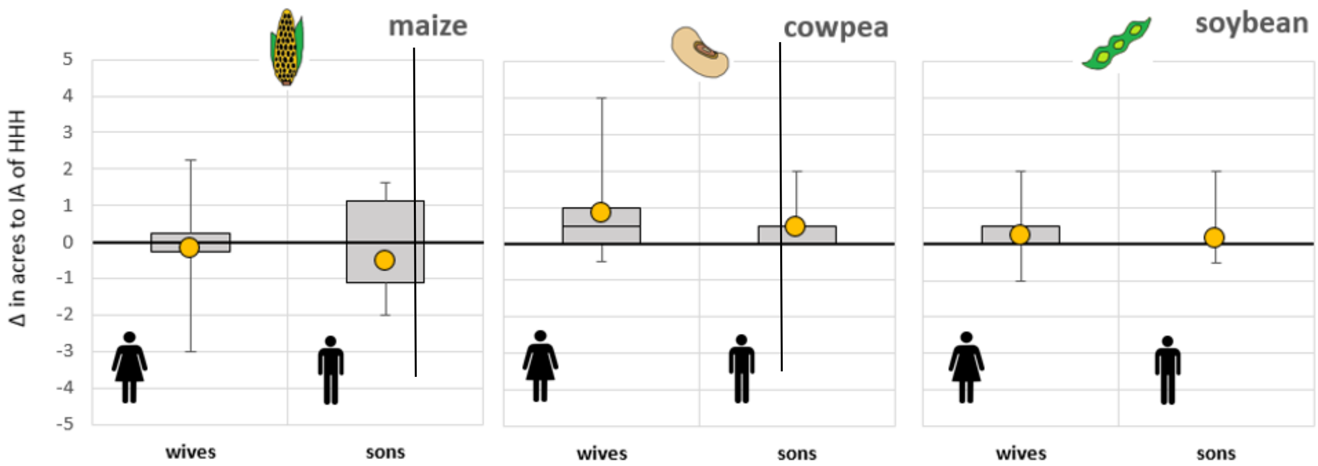


Figure A5.7. Average difference in ideal areas of wives and sons compared to their household heads.

5G. Results. Utility curves and PWU curves

Utility curves and PWU curves for the 18 case-study households: https://www.dropbox.com/s/96oq0i02lmm3iwn/Annex4_UtilityCurves.docx?dl=0

You may also access the data via the QR-code, using a mobile device:

5H. Results. Main reasons for minimum and maximum values of flexibility ranges

The reasons for the minimum ($\eta^{2}=0.230$) and the maximum ($\eta^{2}=0.044$) differed per crop (Fig. A5.8). Securing a sufficient amount of food for home consumption was the most important aspect for cultivating a minimum area of maize, while a combination of covering household food needs and sustaining sales was the dominant reason for a cowpea minimum and sales the main reason for the soybean minimum area. Inputs were the main constraint in growing more maize, while labour was the main constraint for not cultivating more cowpea or soybean.

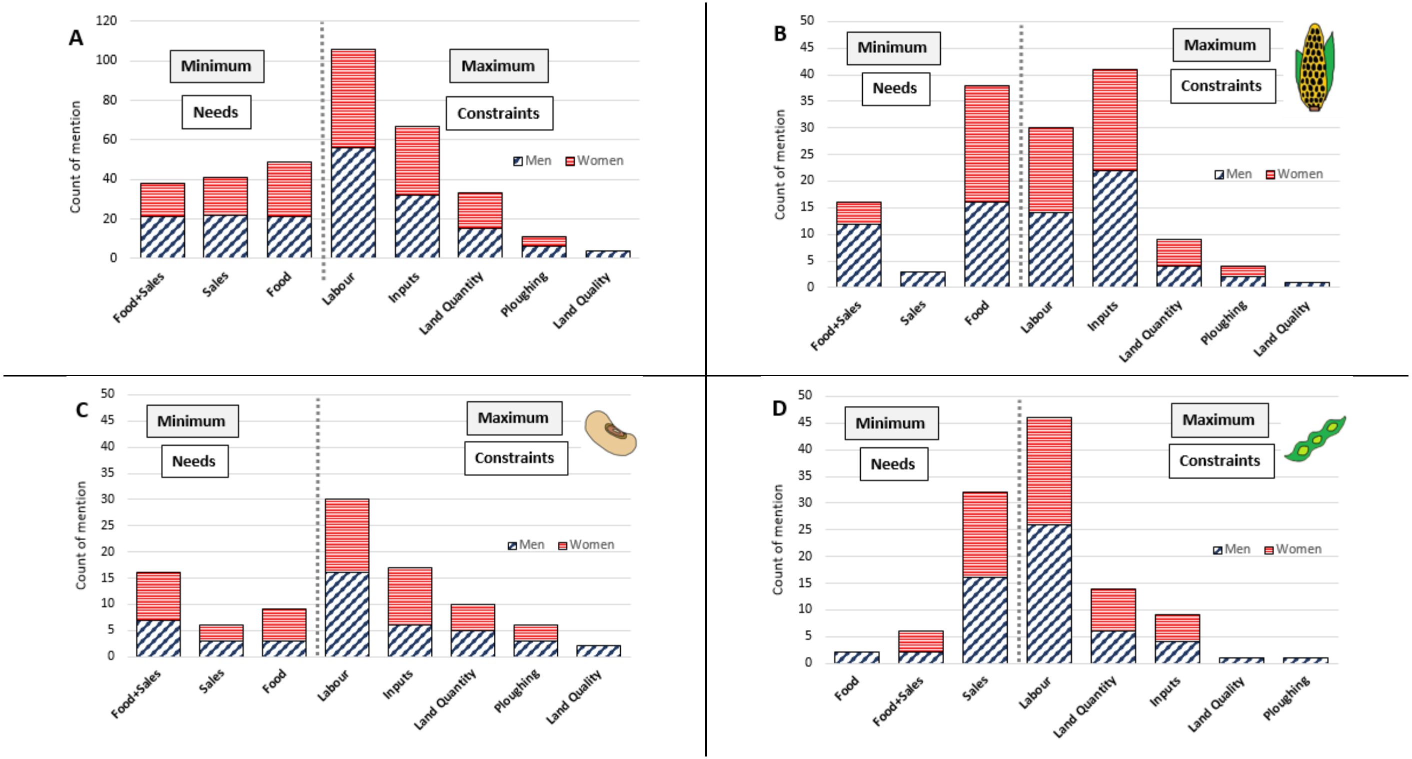


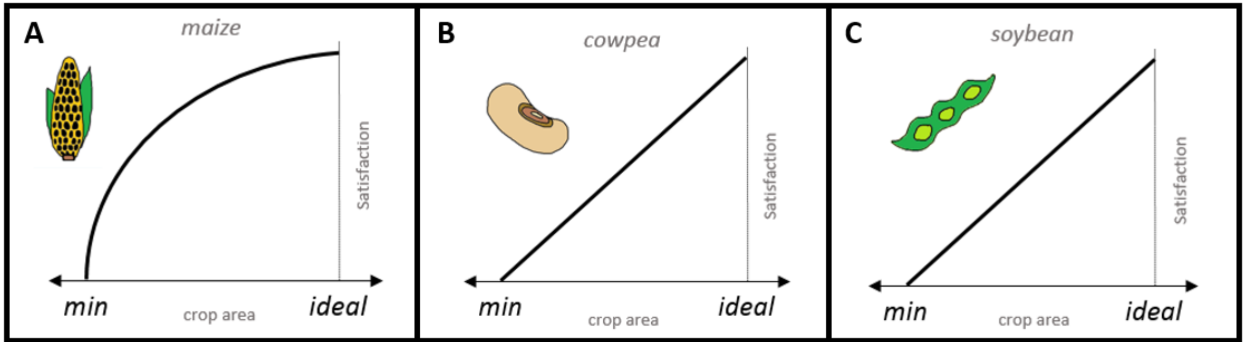
Figure A5.8. *Main reasons for minimum and maximum values of flexibility ranges aggregated for all crops (a), and for individual crops of maize (b), cowpea (c) and soybean (d).*

5I. Results. The curvature

We analysed the utility curvature in order to reveal patterns in satisfaction losses. Among the 174 curves, the convex- and the linear shapes were the most prevalent shapes on both sides (min-ideal, ideal-max) of the curve, indicating the continuance of a relatively high level of satisfaction around the ideal area. When differentiating between min-ideal and ideal-max, we determined a moderate effect of crop type ($\eta^{2=}0.289$) on the min-ideal-shape and a moderate to strong effect of resource endowment ($\eta^{2=}0.308$) and power ($\eta^{2=}0.167$) on the ideal-max-shape. Figure A5.9 and A5.10 visualize the encountered patterns in curvatures for the min-ideal and the ideal-max respectively.

For maize the predominant min-ideal-curve shape was convex, for cowpea and soybean it was linear. Marked differences also existed in the number and type of cut-offs per crop: For maize no male respondent set a cut-off; only two female respondents indicated not to be willing to decrease the maize area. For cowpea and soybean, in 65% of the cases the ideal was equal to zero. Men, more frequently than women, indicated their ideal area for cowpea to be zero.

For the ideal-max-side, a convex curve was mostly associated to members of medium-high resource endowed households and/or household members with a medium to large power share (*Pi*). A linear curve was mostly associated to members of medium resource endowed households and/or household members with a relatively large power share. A concave curve was mostly associated to members of high resource endowed households and/or household members with a small power share. A cut-off (inflexible) curve was mostly associated to members of low resource endowed households and/or household members with a relatively large power share.



Cut-offs	Inflexible	Impossible ideal = 0
Men (N=31)	-	-
Women (N=27)	2	-

Cut-offs	Inflexible	Impossible ideal = 0
Men (N=31)	7	17
Women (N=27)	5	6

Cut-offs	Inflexible	Impossible ideal = 0
Men (N=31)	2	6
Women (N=27)	4	5

Figure A5.9. Predominant min-ideal-curvatures for a) maize, b) cowpea and c) soybean. The tables contain information about the number and type of 'cut-offs' per crop.

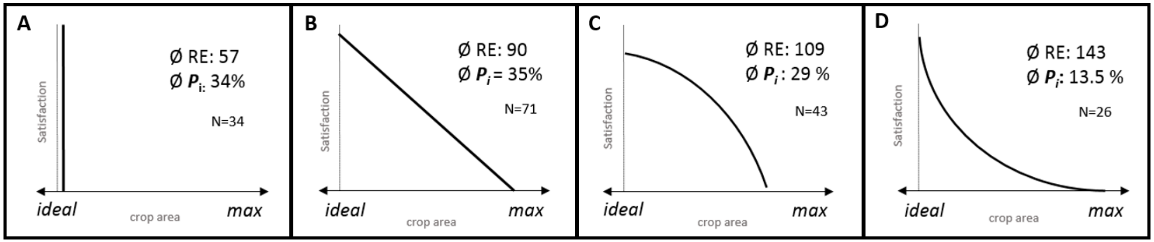


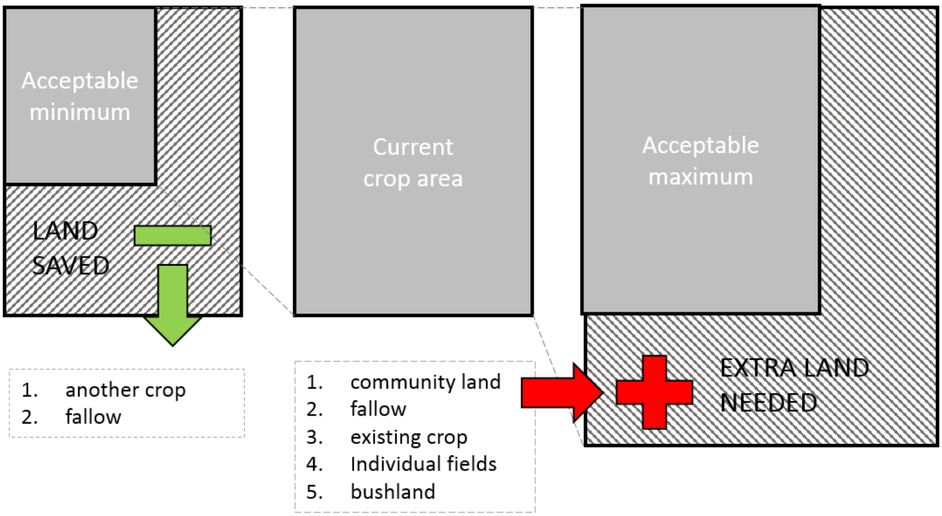
Figure A5.10. Four predominant ideal-max-curvatures as related to average household-level resource endowment (RE) and average individual power share (Pi). The RE score comprises TLUs, total farm land and household size.

5J. Results. Crop-specific implications of areal reductions or increases

When indicating minimum and maximum crop areas, respondents were asked to report associated land-use implications. For area reductions towards the minimum, most respondents (48%) indicated to grow another crop instead or to leave the area fallow (45%). When growing another crop, maize was mostly replaced by soybean or cowpea, cowpea by vegetables and soybean by maize or groundnuts.

When increasing the area towards the maximum, most respondents would ask for land from other members in the community (34%; n=29) or use their own fallow land (24%; n=20). 18% (n=15) of the respondents indicated to compromise an existing crop, 16% (n=14) suggested to use individual fields, 7% to clear bushland (n=6) and 1% to ask for land outside of the community (n=1). In case of compromising an existing crop, maize was indicated to mostly replace soybean (67%; n=2) or cowpea (33%; n=1), cowpea to replace maize (67%; n=6) or soybean (22%; n=2) and soybean to replace maize (100%; n=3). We hence observed an interdependency in land allocation decisions for maize, cowpea and soybean.

The reported implications of an areal increase or decrease were found to vary with the resource endowment ($\eta^{2=}$0.251-0.630) and power share ($\eta^{2=}$0.096 -0.400) of the respondent, *cf.* Figure A5.11.



	Areal decrease	Areal increase
RE — HRE	• save for other crops • fallow	• compromise existing crops • ask for community land • co-opt individual fields
RE — LRE	• **maize / cowpea:** individual land	• fallow or bushland
Power share — high	• **maize:** grazing ground, fallow • **cowpea:** individual land, fallow • **Soybean:** fallow, other crops	• **maize:** fallow, community land • **cowpea:** community land, existing crops • **soybean:** existing crops, community land, co-opt individual land, fallow
Power share — low	• **maize:** other crop • **cowpea:** other crop, fallow	• **maize:** compromise existing crops • **cowpea:** fallow, bush- individual land • **soybean:** bushland

***Figure A5.11**. Implications of areal increases or decreases, differentiated by resource endowment, power share and crop.*

5K. Results. Model-overarching unresolved mismatches

Three model-overarching mismatches (AA≠PA) concern the soybean area: the AA corresponded to the interests of a wife (P_{wife}=0.3), a son (P_{son}=0.1) and a parent (P_{parent}=0.1). More powerful respondents indented to cultivate a greater soybean area, but last-minute resource constraints compelled an areal reduction. The reduction was still being deplored, hence instead of answering 'what was your ideal area under the given conditions' it seems as if powerful respondents mentioned their ideal area under 'normal or desired conditions'. The emotional bias is likely, since the most powerful household members indicated to have no satisfaction at the AA and we hypothesize that if the AA was a calculated compromise, powerful household members would evince at least a minimum level of satisfaction with the actual decision.

5L. Results. Self-reported power shares (deviations)

Per household, we collected as many independent, individual statements and descriptions on power distribution as possible via

- Individual, general descriptions of decision-making processes for land allocation in the respondent's household, see page 2 of the household survey *(typically revealing: who is involved in decision-making? How are the different members involved? Who has the final say?)*

- The stick-score method *i.e.* the direct indication of power shares per household member by each respondent *(we treated the self-indicated power shares as approximations. The individual approximations were considered to be matching (i.e. as an agreement on who held how much power) when deviating less than ±15% in terms of the total power share. We also considered whether or not the ranking (who is the most powerful, 2nd, 3rd etc.?) was congruent among household members.)*

- We also noted down relevant anecdotes on decision-making, provided by the respondents, as well as own (researcher/translator) observations *(e.g. on intra-household* *interactions during the joint mapping exercise: did the wife, the husband, the son etc. appear as a team? Who was dominant and who was silent?)*

Information (*cf.* household survey data) from the above-mentioned sources was used to estimate the actual power shares (*cf.* also Annex 5C). The triangulated estimated power shares were subsequently used for the Newtonian model as well as the utility-power model. We think that, due to deviations in personal experiences and perceptions, in most cases, power shares can only be approximated. Furthermore, a persons' actual influence in a negotiation also depends on his/her 'form of the day' (health, concentration, emotional distractions *etc*.) *i.e.* a person's generally valid power position might not always be present/effective/available to him/her. Power positions are also likely to (somewhat or fully) change in time, based on the personal development of the different actors.

Looking at previous studies: large differences were found in the perception of power distribution between men and women within households: Alwang et al. (2017) interviewed men and women (separately and jointly) on their responsibility for agricultural activities. When interviewed separately, men mostly claimed sole responsibility while women claimed joint responsibility. Being interviewed together, answers were less divergent, but still, large differences in reported perceptions prevailed. Anderson et al. (2017) in Tanzania (N=1851 households) consulted husbands and wives separately on over 13 farming related household decisions. The study identified significant differences between decision-making authority ascribed to wives by their husbands and vice versa. Anderson et al. (2017) refer to previous studies, describing discrepancies between the husbands and the wife's report, too, *e.g.* Jejeebhoy (2002, 2000) who looked at assessments of the woman's level of mobility, her access to economic resources and her decision-making authority. Ghuman et al. (2006) look at data from India, Pakistan, Thailand, the Philippines and Malaysia, concluding that men and women differ in their assessment of women's decision-making authority and in their understanding of the questions (having a final say versus having an input). Bradshaw (2013) revealed that men and women in Nicaragua gave divergent estimates of the women's household labour contributions, with men under-valuing women's income generating activities relative to the self-reports of women.

Concerning our own data: most household members (54/58) do describe power to be divided and do not describe the household head as the sole decision maker on land allocation, although he is usually described as holding the largest power share. According to the stick-score method: only in three (out of 18) households, and within these, by four (out of 58) respondents, the HHH was described as the sole decision maker (10/10 sticks). In only one out of the three households the respective statement of all (two) respondents matched. We furthermore determined the standard deviation (SD) to reveal the variability in individual evaluations of intra-household power distribution. Figure 5.1 of the manuscript indicates the average standard deviation in self-reported, non-triangulated power shares per member in each category. Intra-household evaluations of the HHH's power share deviate by 10%, of the wife's share by 6%, of the son's share by 9%, of the brother's share by 8% and the daughter's share by 0%. There was not enough (n=1) information to indicate the standard deviation for the parent's power share. The average standard deviation in self-reported power shares amounts to 8.1%. This supports the statement that the independently reported power shares are relatively similar and that most household members agree that the HHH is (one of) the most powerful household members, but not the only household member holding power *i.e.* influencing decisions on land allocation. Data on the self-reported power shares as well as the triangulated shares can be accessed online at:

https://www.dropbox.com/s/uhqn0jb93zttgcw/Deviations%20Power%20Shares.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

Annex 6

6A. Introduction to context and social set-up of the game

The participants were addressed in the following manner:

‘We are part of the Africa RISING project. Africa RISING is working with farmers here in Duko since four years. Together, we learnt a lot about technologies for sustainable intensification. A second phase started and it is all about ‘adoption’ *i.e.* we would like to understand better how farmers make decisions. We have come here before and asked ‘whom do we have to consult if we would like to get insight into the diversity of interests and power positions within households?’. We were told to see the male household head (HHH), the wife and the oldest son or daughter. They are like the three stones under a cooking pot *i.e.* the social fundament of a household. We have invited you since you are one of these three members in your own household. We have selected participants from different households because wisdom is achieved when different knowledge comes together.’

‘We would like to play a game with you today and for that matter we will form groups. We would like all male HHHs to sit together, then the women and the young men. Your group each represents one household member. Each group will receive one card, carrying the image of the household member your group represents. In this game, you do not represent yourself, but you represent this household member.’ (*cf.* Fig. A6.1) [We distribute the cards]

'The person you see on the card is part of a medium resource endowed (MRE) household. So that means you should imagine that you are part of this household.' (*cf.* Fig. A6.2)

Figure A6.1. *Impression of introduction given by facilitator and translator Baba Iddrissu Mohammed.*

***Figure A6.2**. The facilitator shows the 'type of household member'- card to the game participants*

6B. Introduction to the case (the farm household)

[Note: in order to reveal differences in choices among household members, we needed to create a hypothetical but concrete and realistic case, that all players could identify with during the game. We used the locally validated farm typology of Michalscheck et al. (2018a) to describe a typical medium resource endowed (MRE) farm household in Duko, since MRE households were found to be the most prevalent local farm type.]

The participants were addressed in the following manner:

'Your household has 9 members: the male household head, 2 wives, two sons, three daughters and the grandfather. All the land of the household has been inherited through the male household head, so he owns the land. However, the wives and sons may ask for an own piece of land. Your household is able to cultivate 10 acres of land in the rainy season. Concerning the land quality: 1.5 acres are located in the valley (suitable for water tolerant crops), 7.5 acres in the 'upland' (with good drainage) and 1 acres is a transition zone between the two (slopy terrain, for crops with some water tolerance/need).'

Figure A6.3. *Drawing of available land resources (quantity and quality) and crop suggestions. This resource map constituted the basis for the individual group work as well as the household-level negotiation.*

***Figure A6.4**. Participants are introduced to possible crop choices. Crop choices were drawn on card and explained by the game facilitator.*

‘Your household has a few goats and sheep and two bikes that help you to buy inputs and to sell your produce. Your farming activity is limited by money and labour. To some degree, community exchange labour helps you to fulfil your farming tasks on time. The oldest son works on other farms as hired labour. He would like to marry eventually, so he needs to save money for that. Assuming that the rain is coming on time, as expected (not too late, not too early): how much of the land area (and of what quality) should be allocated to what crop? Different household members might perceive it differently, so with this game we are trying to understand better who wants to grow what crop and how this translates into actual land allocation. We are looking at the rainy season crops, *i.e.* we skip an eventual dry season vegetable garden. There are also quite some intercrops in Duko but let us refer to the main crops on the map. You can indicate to us later if you would grow anything as an intercrop, we will note it, but not put it on the map.’

[Reflection: after introducing the case we consulted participants on whether or not it was realistic for this farm household to purchase cattle or to expand the crop area. The aim of this consultation was to level the participants' assumptions on the household's resource endowment and its 'room to manoeuvre', so that differences in group level decision-outcomes would truly reflect different interests rather than being based on different assumptions about the household's resource base.]

'We would like to discuss a few questions with all of you to make sure we share the same understanding of the household's resource situation:

Let us assume that your neighbour is selling a cow, but the price is high. Are you going to buy it?

Assuming that someone suggests to you that you should farm more acres (more than 10), discuss the implications for a household like yours (*i.e.* medium resource endowed)'

Modifications to the case?

According to the groups' perception: any modifications to the case study needed in order to be 'typically medium resource endowed'? [We would like them all to be one 'one page', so that their assumptions are the same during the game!]

6C: Introduction to group discussions

The participants were addressed in the following manner:

'Your role!

So each one of you is part of a group, representing a particular member of the MRE household that we just described to you. We are looking at land allocation: given your resources and your interest: what crops would you suggest to grow on the 10 acres?'

[Show them the sketch of the 10 acres (quantity and quality). Show them the cards and give each group a set of cards. They can use any of these crops but they do not need to use them all and if we forgot anything they can suggest additions and we can add them.]

‘We would like to know from each group: how do you think your household member would use the 10 acres: for what crops? Growing them where (what land quality)? To answer this question, we will lead each group to a separate place where you can discuss and come to a consensus on the matter.’

‘Each group has one spokesperson that will then communicate this consensus to the ‘rest of the household’ *i.e.* to the other household members represented by the other two spokespersons. So after your group has chosen how to allocate the ten acres, the 3 ‘household members’ represented by the spokesperson, have to agree, too, but that is the next step and we will lead you there.’

‘At this point of the game, we would like to inform you all about the role of the spokesperson.’

<u>The spokesperson</u>

‘The spokesperson holds a very important role, but he/she does not take part in the discussion within the group! The spokesperson is a neutral person, not an opinion leader. He/she is a good observer and mediator and he/she is good with words (=can express himself/herself clearly).The spokesperson may only interfere in the discussion for summarizing the viewpoints of other group members and leading them towards a consensus. The spokesperson also has the task to make sure that everybody’s opinion in the group is considered, so that it is not the view of one person but the wisdom of different people that he/she will later represent. It is a clear consensus that the spokesperson needs, in order to present it to the ‘rest of the household’ *i.e.* to the other spokespersons, during the negotiation. The role of the spokesperson is a difficult and noble job and that means that the rest of the group should support the spokesperson by working towards a clear, joint position. In the very end of this gathering, we will ask each individual how well he/she felt represented by the spokesperson. So this is a serious job and we beg you to make sure that he/she can do well.

Before you leave into your discussions, we would like to give you a starting point for them. As a first step: think of the role, the typical tasks and duties of your particular household member and how these are related to the crops that you could grow on the 10 acres?'

A starting point for the internal group discussion

'Please think about this: you are investing so much time, energy and money into farming. You do not just do that for the sake of spending time and your money is valuable, so what do you need or want to achieve with your investment? Describe what your household member wants to achieve with it and what he/she needs to produce. Is it food? If so: is it a certain type of food? *E.g.* is it staple crops, vegetables, legumes? Or are your producing crops mainly for sales? And if it is for sales, then what do you need that money for? For food, education, health, clothing...? What needs are you responsible for covering? And what are the 3 most important things that you need money for and that push you to grow certain crops? We will visit your group and ask you about it.'

'Please raise your hand if your group has a question or if you have come to a census (when you are done). Stay in your groups location after you raised your hand, we will come over to you and you will explain your choice to us and we will ask you a few questions before we all gather back together here'

'Any questions? *Questions.* You are ready to go into your groups and start the discussion!'

Space to record questions/observations/take notes:

6D: Template for capturing process and outcome of the group discussions

Instructions to facilitator:

Once a group has reached a consensus, please ask the spokesperson first to explain the decision-outcome. Then please ask the spokesperson all the questions below and afterwards please ask the other group members whether or not they have anything to add or to correct. They can add something and have a last discussion, improving the 'profile' of their household member before the negotiation step. Finally, please ask the spokesperson for a summary and ask all group members whether or not they feel accurately represented by him/her. Please take a photograph of the completed resource map; please fill template below.

Template to record decision-outcome on land allocation

Crop	Land area in acres (%)	Land quality	Why this area (quality, quantity?): what is the purpose of growing this crop (advantages?) Why not more? What are the drawbacks? Why not less?
Maize			
Groundnuts			
Millet			
Cowpea			
Soybean			
Rice			
Yam			
Cassava			
Bambara			
Vegetables			
Sweet potato			

With the choice and composition of these crops, what objectives are you achieving with it?

In how far are you farming for food? And what features are important to you when selecting the food crops?

In how far are you farming for sales and money? And what do you need to buy with that money? Mention the three most important things or services.

Do you think the 'other household members' made a different choice? If so, how would it be different? And what is the reason for it?

Do you think that your household member has limited access to some of the resources needed to grow certain crops? If so: what would that be? For what crops? And what is the reason for it?

6E: Video documentation of negotiation

The video documentation of the negotiation may be accessed online via:

https://www.dropbox.com/s/b9efomv4xvffmgw/Appendix2_Video_Game.mov?dl=0

You may also access the video via the QR-code, using a mobile device:

6F: Debriefing template

Feedback session:

[Ask all other group members separately for their opinion. Template per group of five members.]

ID	From 0-10*, how satisfied are you with the result if you think of the interests of your household member? 0= not satisfied 10= highly satisfied	From 0-10, how much power do you think 'you' had during the negotiations? 0 =none, no influence at all 10= full control, nobody else had And: who had the remainder?	How well do you think the spokesperson (you?) represented the groups' opinion in the discussion? 0=bad/ unacceptable 10=perfectly accurate/excellent	In your household, who has how much power (out of 10)?	In your household: How does the negotiation differ to the one seen in the game?

Differences for LRE (Low Resource Endowed) and HRE (High Resource Endowed) HHs (households)

ID	(How) would land allocation and the negotiation be different in a LRE household?	(How) would land allocation and the negotiation be different in a HRE household?

Note: We use the score-stick method to express satisfaction and power shares: 0 sticks represent no satisfaction or no power and 10 sticks full satisfaction or full power/control (100% decision-making power during the negotiation). For power evaluations: if their own member had less than 10 sticks, they were asked to indicate who held how much of the remaining power (sticks). Ideally it should also be recorded 'what made you think that you have this much and the others had that much?'. If time remains the game members assemble and can exchange about their experience, give feedback on the game or ask questions to us, facilitators.

6G: Written results and notes

The written results and notes of the serious game may be accessed online via:

https://www.dropbox.com/s/pntxowdpt79r54k/Annex%206G.pdf?dl=0

You may also access the data via the QR-code, using a mobile device:

6H: Data. Participant demographics

Data on participant demographics may be accessed online at:

https://www.dropbox.com/s/65m3o36wcw9hbhq/Annex6H_Data_Partici
pant_Demographics.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

6I: Data. Power evaluations

Data on power evaluations may be accessed online at:

https://www.dropbox.com/s/h2vbbosi3ylug7b/Annex6I_Data_PowerEval
uations.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

6J: Data. Video transcription

The video transcription may be accessed online at:

https://www.dropbox.com/s/8ia75dormvw0g0b/Annex6J_Data_Transcri
ptionVideo.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

6K: Data. FarmDESIGN results

The FarmDESIGN results may be accessed online at:

https://www.dropbox.com/s/xu5ai06hjaxayqw/Annex6K_Data_FarmDESIGN%20results.xlsx?dl=0

You may also access the data via the QR-code, using a mobile device:

6L: Data. FarmDESIGN models

The FarmDESIGN models may be downloaded from:

https://www.dropbox.com/s/r4dwlh2gdsmx3w4/Annex6L_FarmDESIGN_Models.zip?dl=0

Acknowledgements

On n'a que le temps que l'on se donne.
You only have the time that you take.

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First and foremost I would like to thank my family, whose intra-household diversity continues to shape my decision-making. My mom, the head of the household. You taught me to think quickly and deeply, with humour, while remaining pragmatic. My dad, our backbone. Complex and impatient while being deeply caring and willing to sacrifice more than anyone ever would. You made everything work for all of us! You and I share the same dilemma of giving so much while running empty at times, putting all the weight on ourselves. I want to travel with you, because I think we deserve a lot and should reward ourselves more often. Malina, you are the epitome of 'good' and 'patient'. You are calm, fun, grounded and the only actual farmer in this family, so far. There is a lot that I can learn from you and I am glad that you are my sister! Matti. Your creative genius has always impressed and inspired me and the entire family! You and I recently also discovered similarities between your physio (fasciae) therapy work and my participatory research and coaching approach: our 'success' seems to fundamentally depend on 'listening to what people already know'. I would also like to thank my grandmother Irene, who seems to have an endless kindness, faith and curiosity. Being very critical and precise, I am sure you would have made an excellent opponent at my PhD thesis defence. Wolfgang, my grandfather, was a passionate cartographer, who, with his adventurous travel stories, was the first one to make me dream about Africa and the Middle East. I would have loved you to be here today. I am fully aware that it is this social family ecosystem that allowed me to grow and to go for so many meaningful life experiences! I am deeply thankful to all of you!

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at Haarweg. We are equally passionate about hunting for discounts and I like how we always find ice-cream-vouchers in the form of 10-Euro notes in our wallets. Baptiste, you played a very important and positive role in my life and my professional development: you are an agronomist, we met in Tunisia and you were the first one to point out the match between my passion for ecology and social sciences with the agricultural discipline. I should visit you in Hamburg and I am looking forward to getting to know Cathy, too! Wytze, while sitting only a few meters apart in Radix we actually only really met each other in Nigeria at the Humidtropics Conference in Ibadan. You quickly became my regular lunch companion, we shared many talks, preferably hiding in the high grass in front of Forum, which is a great seasonal habitat for introverts. I very much enjoyed meeting and getting to know you! I believe we did not have enough dancing opportunities though. Viviana, you were the first friend I made in Basel and I am grateful for the time we shared: it was fun, intense and we gave each other a lot of support. I like how principled, strong yet sensitive you are. You are a fighter, you did not give up and you got accepted at Cambridge University. I am proud of you and I have good confidence that you will do great!

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a holiday, despite all the work that I had to do. Thank you for the company, the talks and for giving me a home!

I had a good time at work, too, so I would like to start by extending a general thanks to my FSE colleagues. It was a pleasure knowing you and working with you all! To add a few individual acknowledgements: Daniel, we only got to know each other better in the final year of my PhD. You introduced me to the poems and short stories of Borges, we shared our artwork and good conversations about life and you surprised me with your high sensitivity in many matters. It was beautiful to know you better! Thank you for looking beyond the nerdy me. Walter, when I think of you I mainly think of a big, warm, whole-hearted smile. You are patient and clever and I enjoyed very much having you as my colleague. I hope we can work together again in the future. Katja, while you left before I started my PhD, you were an important part of my research right from the start. You went to Northern Ghana before I did and laid the ground for my follow-up work. You also have so many of my own character traits, so sometimes it felt like seeing myself in a mirror. I really appreciated to work with you and to know you! You are an inspiring, beautiful person and I hope that we will have the opportunity to work together again, too. Stéphanie, our typology-guru. We spent quite some time just before and during the first year of my PhD, too – I remember good talks and our night out in Amsterdam, after which we missed our last bus and had to walk back home, sharing a single bed in ‘an elderly home’. It is nice that we keep in touch and I am looking forward to meeting Gabriel! Erika, it has been long ago, but you have been the first person at FSE whom I shared a desk with and we also shared many moments playing and not actually playing Squash at de Bongerd. It was great fun and you inspired me with your gaming methodology as well as with your ultra-fast Dutch click-bicycle lock, which, once installed on my own bike, saved me hours of valuable time during my PhD. Roos, I would like to thank you for our personal talks, your hospitality when I was submitting my thesis and your self-made gifts. I always found you very beautiful and strong and I admire you for how you ‘go outdoors’ as well as all of your idealistic, personal initiatives! Please keep it up, it is special and makes a difference! Lieneke, we got quite core-fit during our PhD and I stayed in your apartment for some time with Pong, your cat, which was super nice. Thank you so much for your hospitality, too! Pablito, your good mood and kindness also made a big difference to me during my time with FSE. Thank you! Carl, we have shared field work in Zambia, wrote publications and actually started our PhD together on a similar topic. You have inspired and helped me many times and I would like to thank you for that! Merel, we only knew each other for a couple of months, but we pimped your shrimps and you have been really kind, supportive and fun. I am also grateful that you were understanding of my frequent, anti-social escapes into the empty lab space next door to finalize my thesis discussion. Geertjan, you have been the sunshine in the Radix entrance! It was always great to talk to you, you really made a difference to so many people and also to me! I missed you during the last months of my thesis writing, but I am happy that we still manage to stay in contact! You are a great person, keep shining! Hein, I would like to thank you for the fun talks that we had, the bike rides, the pancakes and the chit-chats at Emmaus. You are special and I love how you smile when you talk about your travels! Keep it up and keep travelling! Gemma, you joined this group for the last bit of my PhD-time with FSE, but I really enjoyed your company! You have been very supportive and we also had many personal talks. Please stay as positive, elegant and charming as you are! Hennie, thank you for making a difference with your humour, for being so outspoken and authentic. Having you around is always refreshing! Ichsani, we did not have much time together, but I was greatly impressed and inspired by you! I admire you for your beautiful enthusiasm and the huge bouquet of high quality skills! You are just amazing and FSE is very lucky to have you!

My promotors: Jeroen, you have been positively grounding me, you were always available, you were critical but you always trusted me. We could laugh together and we shared some extensive, personal talks during our joint bus ride in Nigeria. You have supported me most in the conceptual development of this thesis and I would like to thank you for the massive support that you have given me! Thank you! Pablo, you have also always believed in me and you were a great source of inspiration. One of the first things you told me when I joined FSE was that I could always walk into your office if I had any question. You always encouraged and challenged me. Although I was almost one hour late for my 'Go-no-Go'-meeting, although our Skype often did not work and although I was travelling abroad right when you happened to return to Wageningen, it is simply not true that I did not want to see you! :) I hope one day we still have the chance to go to the field together or to work on a joint project. It was a pleasure to meet you and to work with you!

Rogier, a particularly warm and special thanks goes to you, too! You have given me so many opportunities to communicate my science and 'to shine'. You have always taken time to listen and to meet me as a person, I feel seen and appreciated by you and I feel that you truly care! You believed in me and my coaching idea and you involved me in all kinds of important FSE projects and collaborations. I learnt a lot from you and admire you a lot, as a person and professionally! I am glad that you joined to lead FSE and I do think that you kept your promise, to make us (FSE as a lighthouse) shine again. THANK YOU!

I would of course also like to thank my project partners from Africa RISING: Irmgard, you have known me from my consultancy work for Africa RISING in Zambia before I started with my PhD. You have given me valuable support and the necessary power-backing to successfully conduct my field work in Ghana! Without your confidence, your encouragement and trust in me, I do not think I would have been able to complete my field work as I did. Thank you! Bekele, you have been the person I collaborated most with during my time in Tamale. I would like to thank you for your openness, kindness and all of your genuine support! I needed it and it made a big difference to me! Maybe we still manage to publish some papers together, since we had all these great ideas and all of that data! We should talk to Fred. Baba Iddrisu Mohammed: you have assisted Katja in her field work and you continued the work with me. You are reliable, patient, kind, humble and wise. As Katja said rightly, you are a 'walking encyclopaedia' and I wish we could capture all of that knowledge that you gained in the many years that you have worked with smallholder farmers in Northern Ghana. I hope you stay healthy and blessed! Roger Awpone, you were quiet and did not say much when I met you, but as soon as we started our field work, you surprised me with how well and how quickly you understood and perfectly managed all contents and processes! You are clever and hard-working and you have a huge potential! I am sure your efforts will bear fruits!

Last but not least, I would like to thank the farmers in Zambia, Ethiopia, Egypt and Ghana, who taught me a lot about farming! You were open, kind, patient and generous. You have made this work possible! I dedicate this thesis to you, since it is your work and your life and I hope I accurately represented you, just as you would have liked to speak up for yourself. Thank you!

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About the author

About the author

Mirja was born on the 28th of May, 1987 in Eckernförde in the North of Germany. She grew up on a farm close to the Baltic Sea, together with her sister Malina (1989) and her brother Matti (1991). Mirja spent her childhood building hideaways, visiting the neighbour's horses, climbing into her favourite plum tree, playing on mountains of freshly harvested sugar beets and flying high on a swing built by her father. School did not feel rewarding at first, so Mirja kept silent in class and concentrated on her passion for football. A student exchange to France kindled her excitement for travelling the world and demonstrated to her the real-life-benefits of knowledge acquired at school. Mirja started making better use of her time at school and discovered pleasure in diving deeply into the different subjects. Her grades improved, allowing her to continue to secondary school to complete her A-levels.

Mirja had used every summer to travel abroad, first to the South of France, then to Tunisia. Before starting her B.Sc. in Environmental Resource Management (ERM), Mirja decided to further explore the Arab culture by spending one year in Cairo, Egypt, as an Au-Pair. It was here, in the megacity of Cairo, where Mirja first perceived the millions of social interactions as a physical force shaping everyday life – an experience that later inspired her to analyse household-level decision-making processes using algebra (*cf.* Chapter 5: Newtonian model). In both, her bachelor thesis (on microfinance in Chile) and her master thesis (on water conservation measures in Amman, Jordan), Mirja centrally considered people's perspectives in resource management decisions: why did they opt for a particular way of managing their resources? What were their realities, drivers, concerns and goals? Questions, that visibly shaped this PhD thesis, too.

After completing her M.Sc. degree, Mirja wanted to know 'where to best put her efforts'. In order to explore as many different institutional contexts and topics as possible, Mirja worked as an independent consultant (2012-now) i.a. for the UN FAO (Somalia), the Asian Development Bank (Afghanistan), the European Commission (Pakistan) and ORASECOM (South Africa), mostly on water management issues. Mirja also completed a consultancy for the German Institute of Global and Area Studies (GIGA) on large scale land acquisitions in Ghana. 'Land grabs' mostly failed due to the high fragmentation of customary land, constituting about 80% of Ghana's land area. Mirja concluded that strengthening these 'small units' and local smallholder farm systems would likely be a positive contribution against large-scale, foreign takeovers of land. Furthermore, with agriculture being one of the largest water consumers in most developing countries, doing a PhD in agriculture seemed to be a great addition to Mirja's water management background. With great pleasure, Mirja therefore accepted the position as a PhD candidate with the Farming Systems Ecology Group at Wageningen University & Research in 2014. In 2018, Mirja furthermore completed a training as a systemic coach and change manager at the University of Cologne (IneKo), Germany. The questions and approach taken in this thesis, in fact, align well with the coaching rationale: both, in coaching and in farming systems analysis, the 'family' or 'household' is the main social system under consideration and it is all about exploring people's room to manoeuvre.

Besides working as a consultant and coach, Mirja is a passionate painter and collector of African Art and Antiquities. Mirja is currently exploring the options to put her diverse skillset to a best-possible use.

List of publications

Journal articles

Kuivanen, K.S., Alvarez, S., **Michalscheck, M.**, Adjei-Nsiah, S., Descheemaeker, K., Mellon-Bedi, S., Groot, J.C.J., 2016. Characterising the diversity of smallholder farming systems and their constraints and opportunities for innovation: A case study from the Northern Region, Ghana. NJAS - Wageningen J. Life Sci. 78, 153–166. https://doi.org/10.1016/j.njas.2016.04.003

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Michalscheck, M., Groot, J.C.J., Kotu, B., Hoeschle-Zeledon, I., Kuivanen, K., Descheemaeker, K., Tittonell, P., 2018. Model results versus farmer realities. Operationalizing diversity within and among smallholder farm systems for a nuanced impact assessment of technology packages. Agric. Syst. 162, 164–178. https://doi.org/10.1016/j.agsy.2018.01.028

Alvarez, S., Timler, C.J., **Michalscheck, M.**, Paas, W., Descheemaeker, K., Tittonell, P., Andersson, J.A., Groot, J.C.J., 2018. Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farming system typology development. PLoS One https://doi.org/10.1371/journal.pone.0194757

Michael, B., Swetman, T., **Michalscheck, M.** and Asante, F. 2014. Factors of success and failure of large agro-enterprises (production, processing and marketing): a pilot study; results of case studies in the fruit, maize, and palm oil sectors. African Journal of Food, Agriculture, Nutrition and Development (AJFAND) 13 (5). https://www.ajfand.net/Volume13/No5/Reprint-Factors%20of%20Success%20and%20Failure.pdf

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Book chapters

Timler, C., **Michalscheck, M.,** Alvarez, S., Descheemaeker, K., Groot, J.C.J., 2017. Exploring options for sustainable intensification through legume integration in different farm types in eastern Zambia, Sustainable Intensification in Smallholder Agriculture: An Integrated Systems Research Approach. https://doi.org/10.4324/9781315618791

Reports

Timler, C., **Michalscheck, M.,** Klapwijk, C., Mashingaidze, N., Ollenburger, M., Falconnier, G., Kuivanen, K., Descheemaeker, K., Groot, J., 2014. Characterization of farming systems in Africa RISING intervention sites in Malawi, Tanzania, Ghana and Mali. https://cgspace.cgiar.org/handle/10568/42331

Michalscheck, M., Timler, C.J., Descheemaeker, K.K.E. and Groot, J.C.J. 2014. Characterization of farming systems in Africa RISING SIMLEZA intervention sites in Zambia. https://library.wur.nl/WebQuery/wurpubs/493750

Conference Proceedings

Hemminger, K., Bock, B., Groot, J., **Michalscheck, M.** and Timler, C. 2014. Towards integrated assessment of gender relations in farming systems analysis. Poster prepared for the 2014 Tropentag conference. https://cgspace.cgiar.org/handle/10568/51643

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Publications in Magazines

Michalscheck. M., 2017. May we participate in your lives? D+C. https://www.dandc.eu/en/article/cooperate-well-smallholder-farmers-we-must-understand-what-they-do-and-how-they-think

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6 ECTS)

- Research gaps on smallholder farming systems in developing countries (2015)

Writing of project proposal (4.5 ECTS)

- Complex systems, simple solutions? Identifying patterns in innovation pathways of smallholder farmers in Northern Ghana using participatory systems research

Post-graduate courses (3.6 ECTS)

- Introduction to R; PE&RC (2015)
- Gender training tamale; IITA (2017)
- SDG Conference; WUR (2018)
- Serious gaming expert meeting in Lilongwe, Malawi; IIED/SITAM (2018)

Invited review of (unpublished) journal manuscript (1 ECTS)

- Journal of Rural Studies: farm categorization to identify feasible intensification pathways for Mozambican smallholder farmers (2018)

Deficiency, Refresh, Brush-up courses (12 ECTS)

- Analysis and design of organic farming systems; FSE (2015)
- QUALUS; PPS (2016)
- Serious gaming course (MOOC); Erasmus University of Rotterdam (2018)

Competence strengthening / skills courses (6.8 ECTS)

- Interpersonal communication; WUR (2016)
- Competence assessment; WUR (2016)
- The essentials of scientific writing and presenting; WUR (2017)
- Effective behavior in your professional surroundings; WUR (2017)
- Systemic coaching training; University of Cologne IneKo, Cologne (2017, 2018)

PE&RC Annual meetings, seminars and the PE&RC weekend (2.8 ECTS)

- PE&RC Introduction weekend (2015)
- PE&RC Day (2016)
- Convening PhD symposium session (2016)
- PE&RC Last year weekend (2017)

Discussion groups / local seminars / other scientific meetings (5.5 ECTS)

- EPS PhD Get2Gether (2015)
- AidEx Conference & Exhibition (2015)
- SIAS Group meetings (2015, 2016)
- Organizing lunch meeting on smallholder farming system research as well as on biofertilizers (2016)
- Proposal writing for ‘resilience group’ with Bioversity (2017)
- Consultancy to FSE: on organizational structure to fulfill mission/vision (2017-2018)
- GIZ Ethiopia; presentations and joint proposal writing (2018)

International symposia, workshops and conferences (9.8 ECTS)

- Tropentag; poster presentation (2015)

- Tropentag; oral presentation and workshop given (2016)
- Humidtropics Conference; Nigeria (2016)
- TOPS Knowledge sharing meeting; Bangkok (2018)
- Water security and climate change conference; oral presentation; Nairobi, Kenya (2018)

Lecturing / Supervision of practicals / tutorials (4 ECTS)

- Analysis and design course (2015)
- Farm DESIGN workshop; Zambia (2015)
- Systemic coaching training for students and other PhDs (2017, 2018)

Supervision of MSc students (3 ECTS)

- Comparison of land preparation techniques in Northern Ghana