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Usage of Agricultural Technologies for Soybean and Groundnut

An explorative study of smallholders' usage behaviour and associated financial- and supply-side constraints in northern Ghana

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N2Africa
Putting nitrogen fixation to work for smallholder farmers in Africa

WAGENINGEN UNIVERSITY & RESEARCH

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Abstract

The cultivation of legume crops in combination with targeted sets of agricultural technologies is expected to improve soil quality, reduce the impact of agriculture on the direct environment, and allow farmers to intensify their production and increase their incomes and food security. In this context, the N2Africa programme has disseminated 'tailor-made' input- and knowledge packages in Ghana. To shed light on post-project input usage and the association of input usage with farmers' income, I explore input usage of specified agricultural technologies for groundnut and soybean farmers in 2017. In addition, I analyse to what extent usage behaviour is associated with financial- and supply-side constraints. I find that usage of high-cost inputs is low as compared to low-cost inputs and that farmers have adapted their behaviour to their socio-economic circumstances as well as to the overarching market structure. Furthermore, I find that usage of complete technology packages is often unprofitable under specific circumstances – although this is highly context-dependent. When farmers adapt technology packages, leaving out mineral fertilizer, inoculant or both, the profitability estimates are financially more beneficial in some cases. Adding inoculant always increases profit or decreases loss. In addition, I find evidence that several factors, such as distance to the nearest market town and farmers' risk preference, correlated with usage behaviour of several of the technology components in 2017.

Key words – usage, legumes, financial- and supply-side constraints, Ghana, Africa

Preface

This thesis was written in partial fulfilment of graduation requirements for the MSc program International Development Studies at Wageningen University and Research. This thesis was written within the Economics of Development Group and the Plant Production Systems Group (N2Africa).

I would like to acknowledge the help and guidance of several key people in writing this thesis. First, I want to give special thanks to Dr. Joost van Heerwaarden for providing me with the opportunity to do this research within the N2Africa programme and for guiding me every step of the way. I want to thank Dr. Maarten Voors and Dr. Gonne Beekman for their supervision and provision of useful feedback and suggestions. I would also like to thank the staff of the N2Africa programme in both the Netherlands and Ghana; Dr. Samuel Adjei-Nsiah for aiding me during my fieldwork; Peter, Charles, and Phillip for driving me around in harsh conditions and translating more than 80 interviews. I am grateful to all the respondents – farmers, traders and experts alike, offering their valuable time to provide me with much needed data; and although most will never read this, I dedicate this thesis to them.

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List of Abbreviations

CBA – Cost-Benefit Analysis

GIS – Geographic Information Systems

IITA – International Institute for Tropical Agriculture

ISFM – Integrated Soil Fertility Management

MoFA – (Ghana's) Ministry of Food and Agriculture

RoR – Rate of Return (to investment)

SSA – Sub-Saharan Africa

TCE – Transaction Cost Economics

1 Introduction

Intensification of smallholder farming systems is seen as an important pillar of agricultural development in the developing world for several reasons. It is needed to produce more food to sustain a growing population (World Bank, 2008; Vanlauwe et al., 2014); it is recognized as a major entry point to decrease rural poverty (World Bank, 2008; Vanlauwe et al., 2010) and it can improve the environmental quality of the surrounding area by minimizing nutrient losses to the environment and maximizing crop productivity per unit of nutrient applied. This reduces the pressure to convert additional land for agricultural purposes (Vanlauwe et al., 2010; Aidoo, Mensah, Opoku, & Abaidoo, 2014). Since 1980, agriculture in sub-Saharan Africa (SSA) has not seen significant increases in yields of cereal and legume crops, arguably due to low or declining soil fertility and nitrogen and phosphorus deficiencies (Sanchez et al., 1997; Muchena, Onduru, Gachini, & De Jager, 2005; Fermont, Van Asten, Tittonell, Van Wijk, & Giller, 2009; Tittonell & Giller, 2013; Aidoo et al., 2014). The adoption of Integrated Soil Fertility Management (ISFM) techniques is widely propagated as a solution by public and private actors. It is recognized that ISFM techniques result in improvements in productivity, which in turn may affect household welfare through various pathways, such as improved incomes, increased ability to educate children, and investments in livestock assets (Marenya & Barret, 2007). The rotation of grain legumes, such as groundnut and soybean, in a farming system is perceived as one such technique. Recent studies, conducted as part of the N2Africa research-for-development programme, show significant increases in yield resulting from the production of grain legumes in combination with the implementation of targeted packages of improved inputs[1] (Franke et al., 2014; Mutuma, 2014; Ronner et al., 2016; N2Africa, 2017).

In Asia and Latin America, supply of such improved inputs has been facilitated by associated subsidies and government policies which have made these inputs accessible to a wide range of farmers. In SSA, including Ghana, such policies have often not been in place or they do not function properly. Although subsidy programmes are increasingly reinstituted in Ghana, smallholder farmers appear to have limited access to them (Banful, 2011; Marinus et al., 2016). To promote the dissemination of improved agricultural technologies, the N2Africa program has set up focal adaptation trials (Prieto Bravo, 2016). N2Africa, funded by the Bill and Melinda Gates Foundation, is set up to directly address smallholder food- and nutrition insecurity in SSA, and to increase rural incomes through increased agricultural productivity. This programme is led and coordinated by the Wageningen University and Research Centre and the International Institute of Tropical Agriculture (IITA). Nitrogen fixation is considered key: legume crops capture nitrogen from the air and fix it in the soil. This enriches the soil and reduces the necessity to utilize external inputs such as mineral fertilizer, thereby decreasing the impact of agricultural on the natural environment. During the adaptation trials, farmer cooperatives and communities were targeted and asked to participate on a voluntary basis. Participating farmers in Ghana received a one-time free input-package for groundnut, soybean, or cowpea. These packages included a small amount of improved seed, mineral (phosphorus) fertilizer, and inoculant. In addition, farmers received training on how to implement the

[1] These technology options include combinations of improved legume varieties, mineral fertilizers, rhizobium inoculants, and improved farm management techniques, such as row planting and weeding.

technologies. The idea is that farmers adapt the input packages to their own preference and will continue to purchase and use the technologies in subsequent years.

In this context, the continued use of the promoted improved technologies relies on farmers' willingness and capacity to invest in agricultural intensification. Notwithstanding several recognized adoption determinants, such as risk- and time preference and uncertainty (Feder & Umali, 1993; Marra, Pannel, & Ghadim, 2003; Simtowe, 2006; Ross, 2017), investment in improved technologies is to a considerable extent market-driven (Chirwa, 2005; Marenya & Barret, 2007; Vanlauwe et al., 2010). Commodity sales should provide legume farmers with incentives to invest in (more) agricultural inputs, which, in theory, can provide farmers with higher yields and increased income. However, many seemingly profitable agricultural technologies are not always used (Wossen, Berger, & Di Falco, 2015). Based on field experiences and a review of the academic literature (Chapter 2), I hypothesize that input usage is subject to a set of economic constraints, including financial constraints and farmers' risk preference.

First, smallholder farmers face several financial constraints that determine whether the investment in inputs for grain legumes is efficient and profitable. These include, among other factors discussed in this study, direct- and indirect costs of input application and supply-side constraints. Currently, little is known about the actual costs and benefits of input usage and the associated supply-side constraints, such as the availability of the inputs on the local market. If these factors prevent farmers from making a profit or from purchasing relevant inputs on the market, they will shift their production process and their willingness to invest in inputs for legumes declines (Ross, 2017). In addition, poorer farmers are often those who produce crops for subsistence consumption, but are often unable to produce enough to feed their household the whole year round. Consequently, they require cash to purchase food for consumption, which cannot be invested in agricultural intensification (Frelat et al., 2015). The availability of cash at the beginning of the season is therefore one financial constraint that is specifically considered in this study. In addition, the availability of mediated loans to purchase agricultural inputs – MoFa loan in Upper East Ghana - is expected to positively correlate with input usage, since it can alleviate the latter cash constraint by increasing the access to financial capital (Feder & Umali, 1993; Dzadze, Aidoo, & Nurah, 2012). Last, I consider how farmers' attitude towards risk taking correlates with usage behaviour. Farmers' risk preference can be considered a constraint in that it restricts farmers in making economically rational decisions (Simtowe, 2006).

The importance of the latter constraints and their influence on the usage of seemingly profitable productivity-enhancing technologies is often unknown. Against this background, the following research questions have been formulated:

1. How many of the adaptation trial farmers from 2015 and 2016 have taken up (components of) the originally distributed agricultural technology options for soybean and groundnut in 2017?
2. What are the socioeconomic characteristics of the 2015 and 2016 focal adaptation trial farmers in 2017?
3. What are the costs, benefits, and supply-side constraints associated with usage of the agricultural technologies for soybean and groundnut in 2017?
4. How did financial constraints and farmers' risk preference correlate with usage of several relevant agricultural technologies by the focal adaptation trial farmers in 2017 – taking into account several socio-economic household- and farm characteristics?

This thesis is executed in accordance with the N2Africa programme and uses an ex-post evaluation design to evaluate input usage patterns and determinants in 2017, as well as associated costs, benefits, and supply-side constraints of a set of concrete agricultural technologies that were promoted and distributed during the 2015 and 2016 adaptation trials. I gathered data from two primary data sources. First, I have implemented a household survey to gather data from the 2015 and 2016 focal adaptation farmers[2] whom received an input package for either groundnut or soybean. Second, I interviewed several stakeholders, such as agro-input traders, agricultural extension officers, and experts.

In this study, I explore two critical aspects related to the N2Africa focal adaptation trials. First, I explore current usage rates of several agricultural inputs[3]: "Are farmers using the promoted technology options in the years following the project trials?" In addition, I analyse important socio-economic characteristics of the farmers. Second, I investigate the actual costs and supply-side constraints that are associated with the usage of the inputs and I explore whether the technology options (or components thereof) are available on the local markets. I determine the effect of these factors on the profitability of taking up a complete input package. As a result, I tested the following propositions:

1. Usage of the originally distributed agricultural technology options for soybean and groundnut was low in 2017.
2. For soybean only, potentially low usage is (1) due to high costs of the promoted agricultural technologies for soybean and (2) due to a lack of availability of the inputs on the local markets
3. Three financial constraints and farmers' risk preference are correlated with farmers' usage behaviour of the promoted agricultural technologies in 2017. I hypothesize their correlation to be as follows:
    a. Whether a farmer household experienced food shortage in May 2017 – cash constraint proxy – negatively correlates with usage behaviour.
    b. The distance to the nearest market town - transaction costs proxy – negatively correlates with usage behaviour.
    c. Risk preference positively correlates with usage behaviour – the higher the score, the more willing a farmer household is to take up the distributed technologies.
    d. Access to targeted credit – here the MoFA mediated loan in the Upper East region – positively correlates with usage behaviour.

This study contributes to existing literature and N2Africa in two ways. First, it adds to the voluminous body of academic literature on usage and adoption of agricultural technologies by exploring usage patterns of farmers and analysing their socio-economic characteristics. Second, by investigating the actual costs and supply-side constraints associated with legume related input usage, it contributes to one of the priority areas for research, as recognized within the N2Africa program, namely 'increased availability and affordability of legume inputs' (Marinus et al., 2016). Currently, this research area lacks empirical data. The gathered data allows for analyses

[2] Participating farmers were provided with a one-time, free input package for grain legumes. They were encouraged to adapt the application of these inputs to their own preferences.
[3] Mineral fertilizer (e.g. TSP, NPK, YARA blend), improved seed varieties, inoculant, and farm management practices

on how variation in input availability and affordability between farmers correlates with the targeting of sets of concrete technologies.

Results indicate that usage behaviour is highly dependent on farmers' socio-economic circumstances. Almost none of the farmers (re)used the complete package of promoted technologies in 2017. On first sight, it appears that there are two main reasons for this low usage. First, farmers argued that they lack the financial resources to invest in agricultural technologies. Second, not all the technologies were available on the local markets. Delving deeper into these two topics, I find that usage of complete technology packages can indeed be unprofitable under specific circumstances – although this is highly context-dependent due to the heterogeneity of farming households and their production systems. Adaptation of the technology packages – i.e. not taking up the complete package by a farmer – is predicted to be financially more beneficial under specific circumstances. In addition, I find that several factors, such as distance to the nearest market town and farmers' risk preference, appear to correlate with usage behaviour of several of the technology components in 2017. I suggest a broader look on usage behaviour in similar situations; future projects must link farmers to markets to reduce (transaction) costs and dependency on agricultural extension services.

The remainder of this paper is structured as follows. In Chapter 2 I provide an overview of the implicit theory behind usage – 'adoption' in the literature - of agricultural inputs for grain legumes as well as on related direct- and indirect costs and supply-side constraints. In Chapter 3 I discuss the methodology used for this study, including the study area, sampling and data collection methods, and threats and challenges. I present my data and associated descriptive statistics in Chapter 4. In Chapter 5 I provide a Cost-Benefit Analysis (CBA). I present my empirical strategy and the results of several econometric estimations in Chapter 6. In the final chapter I discuss and link my findings.

2 An Overview of the Academic Literature

2.1 Introduction

The topic of this study is closely related to literature on the usage, or *adoption*, of agricultural technologies. In this chapter I will briefly discuss this literature and its theoretical concepts. To understand the mechanisms behind investment patterns of smallholder farmers it is important to grasp the numerous (unobservable) factors that determine adoption of agricultural technologies. Partially, the diverse nature of smallholder farming in SSA is key; there exists heterogeneity in socio-technical conditions, farm types, production objectives, and the biophysical environment (Tittonell, Vanlauwe, Leffelaar, Rowe, & Giller, 2005; Chikowo, Zingore, Snapp, & Johnston, 2014; Vanlauwe et al., 2014). In addition, there are other adoption determinants that I will discuss in this chapter. First, I will forth several widely recognized determinants of adoption. Second, I will discuss the relationship between financial constraints, supply-side constraints, and the adoption of agricultural technologies. Concerning financial constraints, I give special attention to heterogeneous adoption costs, including opportunity- and transaction costs. Regarding supply-side constraints, I give special attention to access to credit. Third, I address the relationship between input usage and farmers' risk attitudes and their capacity to bear risk. I conclude with a brief discussion on how the concepts are linked.

Important to note is that I make a slight distinction between 'usage' and 'adoption'. When a farmer adopts a technology, one can argue that it involves a new technology and that he or she will continuously implement it for the foreseeable future. This is, however, an assumption I cannot make; many smallholder farmers in SSA make the decision of technology adoption separately each consecutive season (Ronner, Descheemaeker, Almekinders, Ebanyat, & Giller, 2017). For the sake of this study I therefor analyse *usage* in 2017. I do not say that the technologies are new to farmers or predict that farmers whom have used the technology in 2017 will also use it in 2018 and subsequent years. Nevertheless, since relevant literature mainly uses the term adoption, I will do the same in this chapter. Furthermore, I consider usage at the micro-level and I investigate individual farmer-household decision behaviour (Feder & Umali, 1993). Moreover, I differentiate between the decision to use an input – a dichotomous choice – and the extent or intensity of usage (Simtowe, 2006). I focus mainly on the former.

2.2 Adoption determinants for agricultural technologies

When dealing with the introduction of technology packages, which include multiple and varying, but also interrelated components, the farmer faces several distinct technological options. The literature on adoption and diffusion processes of agricultural technologies in SSA recognises a range of determinants and constraints related to these options. These determinants are significantly numerous and can roughly be ordered in the following categories: farmer- and household characteristics, resource endowments (human-, physical-, social- and financial capital), (transaction) costs of adoption, market structure, technology type, agro-ecological conditions, uncertainty, and risk- and time preferences (Feder & Umali, 1993; Makhura, 2001; Marra et al., 2003; Chirwa, 2005; Tittonell et al., 2005; Simtowe, 2006; Marenya & Barret, 2007; Mwaura, Muwanika, & Okoboi, 2010; DiFalco & Bulte, 2013; Wossen et al., 2015). I will briefly forth some of the indicators that are regularly included in each of these categories.

Farmer and household characteristics include age, gender, education, and number of adults in the household. *Resource endowments* concern a broad range of factors including farm size, land tenure status, labour capacity, kinship size, per capita (off-farm[4]) income, availability of cash, ownership of assets, and access to credit. Related to the latter category are *costs*, which entail (heterogenous) adoption costs and other transaction costs, which are discussed in more detail in section 2.2.2 and 2.3. Transaction costs, in turn, result from *market structure,* which determines access to extension services, credit, inputs, outputs and information. This includes infrastructure-related factors such as distance to the nearest market and road conditions. *The type of technology* itself determines, to a considerable extent, associated costs and risks, and as such affects adoption decisions. *Agro-ecological conditions* include climatic and weather-related factors. Finally, *uncertainty* and *risk- and time preferences* influence adoption patterns and are discussed in section 3.1.3.

Originally, the factors farm size, land tenure, age, and income were found to be the main determinants of adoption. Strasberg et al. (1999) show how the use of fertiliser nutrients depends on the distance to a motorable road, the value of agricultural equipment owned, the value of the livestock owned, and other human resource factors (as cited in Makhura, 2001). Recent attention has shifted beyond these factors. Currently, widely recognized *economic determinants* of adoption are information barriers, supply-side constraints such as limited access to input- and credit markets, and heterogeneity among households in terms of adoption costs (Wossen et al., 2015). Additionally, there is increasing attention for risk preference and uncertainty (Feder & Umali, 1993; Marra et al., 2003; Simtowe, 2006), social capital (DiFalco & Bulte, 2013; Wossen et al., 2015), and social learning and learning-by-doing processes (Ross, 2017). Social capital, such as the size of kinship within and outside the village, can influence adoption of innovations by reducing market inefficiencies, such as missing markets for credit, and supply-side constraints of adoption (Wossen et al., 2015). Learning processes, including information transfers and learning-by-doing approaches, stimulate farm output stemming from the adoption of improved inputs and management processes (Ross, 2017).

The focus of this study is mainly on the relationship between financial- and supply-side constraints and adoption behaviour; and I give special attention to heterogeneous costs of adoption, the availability of cash at the beginning of the season and access to credit. I will discuss this relationship in the following sections. Afterwards, I will discuss the importance of risk preference and uncertainty.

2.3 Financial- and supply-side constraints

The financial circumstances of a farmer are largely reflected in his or her (access to) wealth. Wealth, in turn, is a recognized adoption determinant; rich farmers tend to invest more and farmers with low returns are expected not to adopt innovative technologies (Marenya & Barret, 2007; Suri, 2011). Changes in wealth depend, among other factors, on two economic determinants: heterogeneous adoption costs and supply-side constraints. These determinants therefor logically serve as a base for adoption decisions and influence the expected future value of investment. This value must outweigh the associated sunk- and opportunity costs if adoption is to be considered profitable. The relationship between the two economic determinants and adoption can be considered as follows.

[4] Income from cropping, livestock, casual on-farm labour (work on other people's field), casual off-farm labour, pension, remittances, salaried job, trade/business

2.3.1 Financial constraints and costs of adoption

2.3.1.1 Profitability and cash constraints

First, one can look at the rate of return (RoR) of investment. Subtracting heterogeneous (production) costs from the additional benefits that result from technology adoption determines whether a venture is considered profitable and, subsequently, how it changes farmers' wealth. Under the assumption that farmers are acting as economically rational agents, profitability influences adoption behaviour to a considerable extent (Suri, 2011). If, for example, smallholder farmers are – or perceive that they are - unable to generate (future) profits with the usage of a technology, they will likely not adopt it. Two main heterogeneous costs that influence the profitability of adoption are opportunity- and transaction costs. I will discuss these in more detail in sections 2.3.1.2 and 2.3.1.3.

In addition, one must take into account farmers' cash endowments at the beginning of the rainfall season. Even if last year's production decisions were profitable, a farmer may not (be able to) save enough cash to purchase new agricultural inputs in the next year or may have a high rate of time preference, such that the farmer rather utilizes available cash sooner than investing it in inputs of which the benefits can only be collected in a year. Moreover, many smallholder farmers experience *food shortage* in at least some months of the year (discussed in Chapter 4). If this occurs at the beginning of the rainfall season – around May, it may severely hamper farmers' incentive to invest in agricultural technologies. These farmers have to choose between purchasing foods to feed their household or purchasing technologies for the coming season; of which they will only reap the benefits in 6 months. Poorer farmers often have to make these choices because they depend more on subsistence consumption. Consequently, they may be unable to generate enough cash to invest in agricultural technologies or are unable to pay back loans (Frelat et al., 2015). I consider these cash-constraints in my analysis of usage behaviour in Chapter 6.

2.3.1.2 Opportunity costs

Opportunity costs are understood as what is given up getting and utilizing, in this case, agricultural technologies for legumes (Krugman & Wells, 2013). For the purposes of this study, I consider the opportunity costs of labour. The adoption of agricultural inputs for legumes increases the demand for labour; there is more on-farm work in implementing the technologies and the household must spend time on searching and buying relevant inputs. The time that is spent on getting inputs from its source (e.g. the market) and the labour (time) that is spent on applying inputs and additional farm management practices could have been spent on something else - say, casual off-farm work. Theoretically, the pay-off that this foregone casual off-farm work could have provided instead of the on-farm work related to the adoption is an opportunity cost. As such, I calculate the opportunity cost of labour as the time given up getting and applying the inputs multiplied by a mean shadow wage of casual off-farm labour (1.99 US$[5]). Note that the opportunity costs of labour do not per se vary between households. I therefore use secondary data on the amount of time that is needed (hours/ha^{-1}) to implement new agricultural technologies.

2.3.1.3 Transaction costs

There are several other (hidden) costs related to the adoption of agricultural technologies. These are the costs specifically related to the *transactions* involved when purchasing and adopting the inputs. Transaction costs have

[5] See Chapter 5

been studied intently over the last decades and Transaction Cost Economics (TCE) theory can be applied to different academic fields. I will briefly discuss transaction cost theory and I will narrow down to transaction costs related to smallholder farmers' input-market participation.

a. Transaction Cost Economics. It is argued that when actors engage in economic activity this never occurs without friction. In other words, there are costs related to market transactions (Coase, 1937, 1960). A transaction, here, is when a good or service is transferred across a 'technologically separable interface' (Williamson, 1981, p. 552). TCE acknowledges both the importance of institutions, which minimize costs, and the assumption that self-seeking individuals attempt to maximize an objective function (i.e. utility) subject to constraints. Moreover, neoclassical assumptions, such as perfect information, zero transaction costs, and full rationality are relaxed, which effectively 'allows' for the friction related to economic activity that is described by Coase (Matthews, 1986). Transaction costs are the embodiment of this friction - they impede and obstruct the formation of perfect markets (Arrow, 1969 as cited in Williamson, 1981) and result in failure to participate in commodity markets (Goetz, 1992).

Transaction costs can either be fixed or variable (Key, Sadoulet, & Janvry, 2000; Ouma, Jagwe, Obare, & Abele, 2010; Alene et al., 2008), and observable or unobservable (Williamson, 1981; Ouma et al., 2010). Three critical dimensions are recognized to describe transactions: *uncertainty* related to transactions; the *frequency* with which transactions recur; and the degree to which investments are specialized to a transaction, also named *asset specificity* (Williamson, 1979b as cited in Williamson, 1981; Williamson 1998). There are three ways in which asset specificity can arise: site asset specificity, when a transaction is linked to a location; physical asset specificity, when the good/asset requires specialized application; and human asset specificity, when agents need to possess or learn a set of skills to use the asset. Furthermore, TCE includes two behavioural assumptions. First, human agents are subject to *bounded rationality,* implying that rational decisions are limited due to the specific decision problem, time, and/or the limitations of the human mind. Second, at least some agents are given to *opportunism*, meaning they can take advantage of a specific transaction for their own benefit (Williamson, 1981).

b. Farm-to-market transaction costs. While the original TCE theory is used to identify alternative modes of governance, the paradigm can also be implemented to analyse the organization of individual agricultural transactions and the behaviour of smallholder farmers (Makhura, 2001). As mentioned above, institutions serve to minimize transaction costs. However, many of the formal rules of behaviour that can facilitate market exchange are missing in developing countries. This can lead to market failure and incomplete markets caused by high transaction costs and information asymmetries (Idem.). Subsequently, one of the biggest barriers restricting smallholder farmers from accessing markets and productive assets – such as inputs and technologies – is considered to be transaction costs (Alene et al., 2008). In this study, I deal with idiosyncratic transactions, since the specific identity of the parties involved - farmers and market-dealers - have cost-bearing consequences. Transaction costs decrease the price received by the seller of inputs, while they increase the price paid by the buyer of the inputs (Makhura, 2001). As a result, non-marketability problems can arise for several reasons (Williamson, 1981). In the next paragraphs, I will discuss these reasons and I will derive several variables that are widely used to estimate transaction costs.

First, when considering agricultural input markets there is asset specificity in the form of site asset specificity. The involved parties are in different geographical locations, which results in *transportation costs* related to accessing input and output markets, as well as labour and credit markets. Inadequate access to these markets is recognized as a major constraining factor of intensified legume production (Al-Hassan et al., 2006; Berchie et al., 2010). Evidence indicates that for small-scale farmers whom reside in remote areas, transportation costs likely represent important market-to-farm transaction costs and are reasonable first approximations of these costs in smallholder farming regions (Binswanger & Rosenzweig, 1986 as cited in Omamo, 1998; Omamo, 1995 as cited in Omamo 1998). If transportation costs are sufficiently high, farmers may decide to devote resource to low-yielding crops instead of (cash) crops with higher market returns (Omamo, 1998). Staal, Delgado, and Nicholson (1997) add to this that one should also consider increased information costs and risk.

Second, the specialized inputs and technologies that are required are linked to what is called physical asset specificity; the assets involved - agricultural inputs and technologies - have little or no general purpose outside the buyer-supplier relationship (Walker & Weber, 1984). Again, this can lead to higher expenses, because to use such technologies one would need to get additional training or education. Finally, implementation of the technologies involves learning-by-doing. This form of human asset specificity results in extra costs due to foregone opportunities, time-allocation, and labour costs and requirements.

Distinguishing between fixed and proportional transaction costs, Goetz (1992) provides several proxy variables to measure transaction costs regarding farmer market participation. These are the ownership of carts for transportation of grain to the market; the physical distance from the market; the regional dummy variables; and access to information. In addition, one can consider screening costs, related to the uncertainty about the reliability of potential suppliers or buyers and the uncertainty about the actual quality of the inputs. Perceived risk is related to screening costs and is arguably another indicator of transaction costs (Drabenstott, 1995 as cited in Makhura, 2001, p. 44). Harder to estimate among the latter indicators are the unobservable transaction costs, which include most screening costs, costs of information search, bargaining, monitoring, co-ordination, enforcement, and product differentiation (Makhura, 2001). Evidently, not all these unobservable costs are relevant for this study. Education and contact with extension can be used as proxies for information, since these factors allow for better access to and processing of available information. Membership of a farmer association can serve as a proxy for bargaining as well as risk, since it reduces farm-level transaction costs of both input and credit acquisitions (Kelly, Adesina, & Gordon, 2003).

Makhura (2001) points to one important caveat; when transaction costs are sufficiently high so that they prevent exchanges from occurring, the costs, by definition, cannot be observed because no transaction takes place. When a farming household does not participate in the market, direct transaction costs, such as transportation costs, are not realised. Furthermore, since not all costs are observable, it is difficult, if not impossible, to give a true estimation of transaction costs. Besides, transaction costs are agent-specific (Wang, 2003) and input-specific. As I will explain in Chapter 5, to solve for this problem I construct scenarios based on the available data.

2.3.2 Supply-side constraints

Besides facing several financial constraints, such as the limited availability of cash, farmers may face supply-side constraints, such as inadequate access to input, output, credit, and labour markets (Al-Hassan, Sarpong, &

Mensah-Bonsu, 2006; Berchie et al., 2010; Suri, 2011; Vanlauwe et al., 2014). These supply-side constraints cannot always be translated into 'monetary costs', but they can increase (transaction) costs significantly and may severely hamper the profitability of investments in intensified legume production techniques (Duflo, Kremer, & Robinson, 2008).

One relevant supply-side constraint in this case is access to financial capital or credit (Feder & Umali, 1993; Dzadze et al., 2012). As I mentioned earlier, farmers are in need of cash to purchase agricultural inputs at the beginning of the rainfall season, but liquid cash is often unavailable in this period. Access to credit can help overcome this cash constraint and therefore plays a key role in agricultural development. For this reason, limited access to credit has been recognized as a major constraining factor for agricultural intensification in Ghana (MoFA, 2007). Consequently, the Government of Ghana has made an attempt to increase farmers' access to financial capital (Dzadze et al., 2012). One measure to increase access to credit is a loan mediated by the Ministry of Food and Agriculture (MoFA). Agricultural extension officers provide farmers with the opportunity to purchase subsidized fertilizer with a loan from one of the rural banks (field note, November, 2017). The effect of this loan on usage behaviour is discussed in Chapter 6.

A consequence of financial- and supply-side constraints is that seemingly profitable technology options often have low adoption rates (Wossen et al., 2015). This can be due to inconsistent patterns of profitability for certain legumes in SSA (Dogbe et al., 2013), which makes it hard to estimate a generalized cost-benefit model. I discuss such a cost-benefit model in Chapter 5. If adoption is unprofitable farmers cannot generate cash with their farm; cash that could be used to invest in agricultural technologies. One safety net is to provide farmers with credit. Alternatively, there may be other factors that lead to low adoption rates, even when technologies are considered profitable. Among these are risk preference and uncertainty, which I discuss in the following section.

2.4 Risk preference and uncertainty

It is recognized that farmers' production decisions are subject to a degree of perceived or objective uncertainty (or both) regarding the effect of innovative technologies on future production (Feder & Umali, 1993; Simtowe, 2006). Farmers deciding whether to adopt agricultural technologies are subject to several risk-bearing factors, such as (subjective) yield distributions, price variability, climatic conditions, complexity and availability of the technologies, and provision of information. Literature on these factors recognizes that poor farmers are often risk-averse and that risk preference is a key determinant of adoption of agricultural innovations (Simtowe, 2006). As previously discussed, the expected future value of investment must ideally outweigh the associated sunk and opportunity costs. However, due to the uncertainty related to both future production and the costs associated with adoption, the eventual payoff is stochastic and unsure. To overcome this, potential adopters must *risk* investing valuable resources in a technology with an uncertain payoff (Marra et al., 2003). If investment fails due to any factor the farmer loses the invested resources. Consequently, the level of risk aversion of the farmer and his or her capacity to bear those risks influences individual adoption behaviour (Feder & Umali, 1993; Marra et al., 2003; Simtowe, 2006; Wossen et al., 2015).

Several variables can serve to proxy for risk preference (Moscardi & de Janvry, 1977). First, older farmers are less prone to take risk. Second, farmers with higher levels of education are more willing to take risk. Third, family size can affect risk preference in two opposing ways. It can either increase risk taking because of increased labour capacity, or it can decrease the willingness to take risk when the farmers' focus is on subsistence consumption. The same can be argued for the level of social capital that a farmer possesses (e.g. the number of relatives in the village) (Wossen et al., 2015). Fourth, a farmer with more land has a higher capacity to bear risks. Fifth, off-farm income increases farmers' capacity to bear risk and allows the farmer to undertake risky adoption. Finally, membership of a cooperative helps farmers to better sustain risk. Family size and membership of a cooperative are also understood as proxies for social capital, which is recognized to reduce the effect of market imperfections, such as missing markets for credit and insurance, on adoption (Wossen et al., 2015).

In addition, subjective ideas about future benefits are vital to understand farmers' risk preference. Herein lies a link to agronomics. Especially with relation to mineral fertilizer there is increasing recognition that fertilizer adoption is influenced by crop response rates - the rate at which farmers convert fertilizer into food (Jayne & Rashid, 2013). Variation in crop response rates to input application and unpredictable weather conditions increase farmers' uncertainty regarding (subjective) future payoffs of investments and related sunk costs (Marra et al., 2003; Berchie et al., 2010; Jayne & Rashid, 2013). Due to high soil quality heterogeneity in SSA, not all fields respond the same to fertilizer application, leading to high variability in the crop response rates (Kihara et al., 2016). This translates itself into different profitability functions for individual farmers. Limited farmer knowledge on the soil quality of their fields increases the uncertainty surrounding additional yield gains of fertilizer application. The same can be argued for inoculation response, which is argued to vary significantly and results in considerable variability in yields (van Heerwaarden et al., 2017). Argued is that variability of actual and observed responses to inoculation may affect farmers' willingness to adopt. Depending on farmers' risk preference and their capacity to bear risk, the variability in crop response rates to fertilizer and inoculation results in a (subjective) prediction of future benefits that affect adoption behaviour. In addition, expectations about (variable) input prices, availability, and quality can translate into uncertainty.

2.5 Link between the concepts

In Figure 2.1, I visualize the relationship between the theoretical concepts that I discussed in this chapter and how they are linked to my research questions and this thesis. Basically, my thesis consists of three parts. The first, descriptive part is to analyse the usage rates of a set of concrete technologies for legumes and the socio-economic characteristics of the farmer household. Here I focus on 'Usage, 'Farmer', 'Household', 'Resource endowments', and partially on 'Market structure'. Second, I reconsider the profitability of usage. In this part I focus mainly on 'Profitability' and 'Financial constraints', taking into account the 'Nature of smallholder farming' and the 'Market structure'. Last, I aim to analyse the effect of several adoption determinants on usage behaviour within the targeted population. The chosen determinants all fall in at least one of the categories presented in figure 2.1. For example, the effect of farmers' risk preference on usage behaviour in 2017 falls under the 'Farmer' category. In the next chapter I will discuss where and how I gathered my data and how I used it to operationalize the three parts of this thesis.

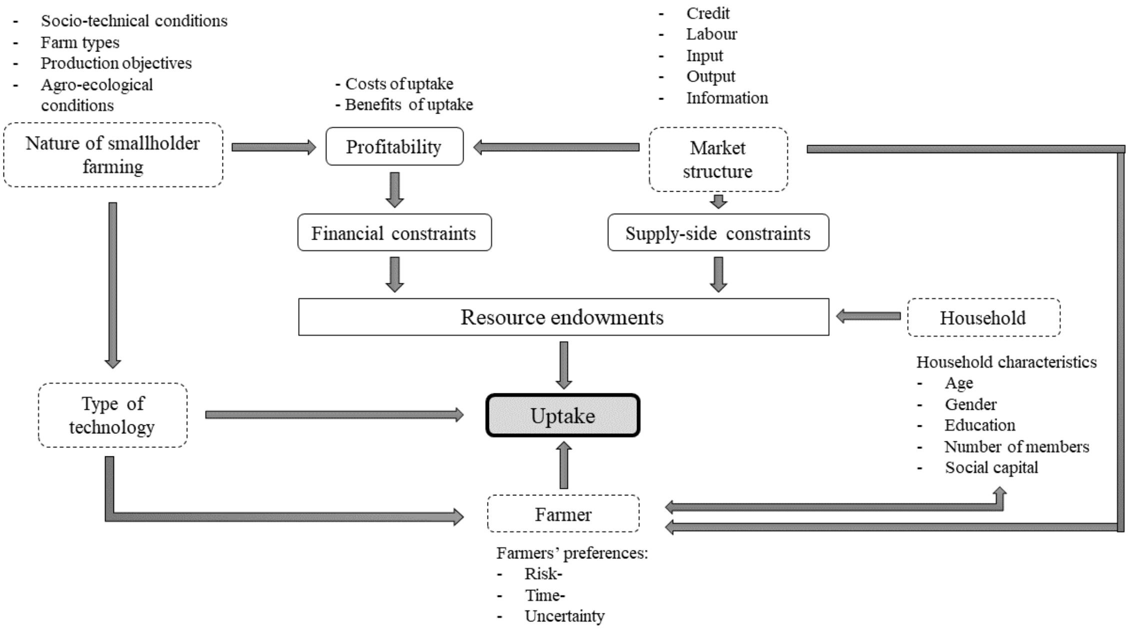

Figure 2.1 *Overview of the theoretical concepts*

3 Research Design

In this chapter I discuss the research design of this study. First, I discuss the study area. Second, I go into my data sources, sampling methods, and data collection methods. I use two primary data sources: a household survey and stakeholder interviews. In addition, I use several secondary data sources. Last, I discuss several threats and challenges related to the methods I used for this study.

3.1 Study area: Northern and Upper East Ghana

My study is set in northern Ghana. The target regions are the Northern- and Upper East regions. More specifically, I have targeted focal adaptation trial farmers and stakeholders from the districts Savelugu, Yendi, Bawku Municipal, Bawku West, and Binduri. These study sites were chosen because most of the focal adaptation trials by the N2Africa programme have been implemented here in 2015 and 2016. The districts in the Northern region (Savelugu and Yendi) are in a Guinea savannah agro-ecological zone, while the districts in Upper East region (Bawku Municipal, Bawku West, and Binduri) are in a Sudan savannah agro-ecological zone (Rhebergen et al., 2016). Temperature is generally high, between 21 and 41 degrees Celsius (Dogbe et al., 2013). There are two main farming seasons: the rainy season, which lasts from May to October, and the dry season, which lasts from November to April. Average rainfall in the Northern and Upper East region between 2001 and 2010 has been 937 and 947mm, respectively (Nakasake, 2016). This study focusses on the rainy season. In the Upper East region land is generally scarcer (field note, October 15, 2017).

The main target population in this study is smallholder legume farmers. Smallholder farmers form about 90 percent of Ghana's agricultural sector and produce 80 percent of the sector's output (Dzadze et al., 2012). An N2Africa early impact survey shows that cropping is an important source of income (Stadler, van den Brand, & Adjei-Nsiah, 2016). In 2012, 86 percent of the early impact respondents produced soybean, while 61 percent of the respondents grew groundnut. Especially soybean is a relatively new crop in Ghana and has begun to play a key role in smallholder agriculture, although the cultivation is not always profitable (Dogbe et al., 2013). However, a variety of other crops are produced, often in combination with legumes. The main crops are maize, yam, cassava, rice, sorghum, millet, cowpea, groundnut, soybean, and tomatoes (Nakasake, 2016). The economies of the regions are still heavily dependent on agriculture (Dogbe et al., 2013).

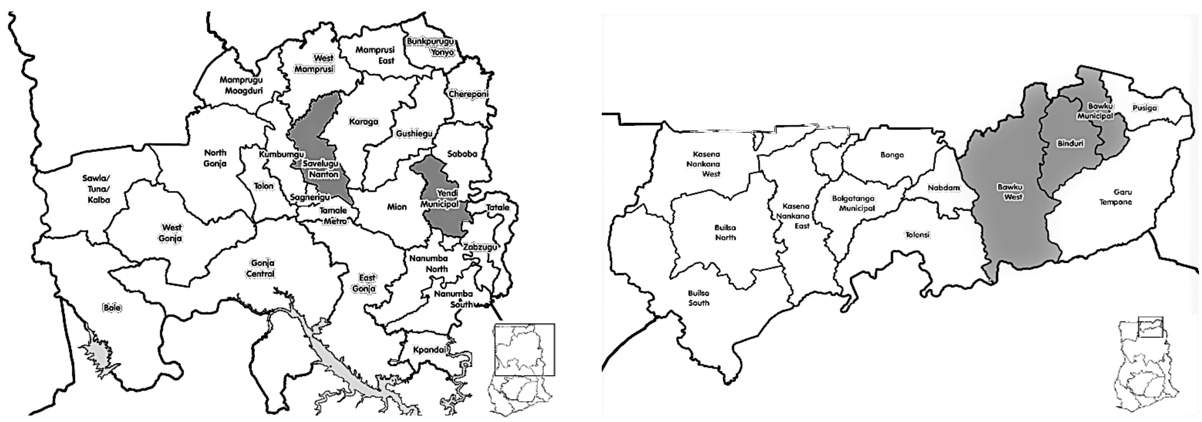

Figure 3.1 *Targeted districts in (a) the Northern- and (b) the Upper East regions of Ghana.*

3.2 Data collection and sampling

In this section, I discuss my data collection methods and the targeted populations. All respondents have been informed regarding the topic and purpose of my study, and they have given their consent to provide information, whilst remaining anonymous outside the N2Africa programme. N2Africa does keep some data regarding personal identification of the farmers. I have respected farmers' decision not to participate or to abstain from answering particular questions.

3.2.1 Primary data

Follow-up household survey

To gather information on usage patterns and associated costs and benefits, I conducted a household survey. I surveyed 78 of a non-random selection of 2015 and 2016 focal adaptation trial farmers. Due to limited available data from the focal adaptation trials in 2015 and 2016, only a relatively small non-random sample of adaptation trial farmers was available for this follow-up survey. The total sample was 101. I attempted to survey each of these farmers, but due to attrition, 23 farmers were not interviewed. I selected the sample based on the package received during the focal adaptation trials (for soybean or groundnut) and location (district). Five districts were selected in collaboration with the International Institute of Tropical Agriculture (IITA), namely Savelugu, Yendi, Bawku Municipal, Bawku West and Binduri. The household survey consisted of face-to-face, structured interviews. I conducted these interviews together with local IITA personnel and people from their partner organisations using Open Data Kit (ODK) software. In the household survey I enquired about the following issues:

- household characteristics and household endowments;
- usage patterns of relevant agricultural inputs for soybean and groundnut;
- heterogeneous usage costs;
- access to markets, agricultural services and information; and
- risk preference.

I determined the relevancy of the issues through the literature review in Chapter 2. The gathered data is used to estimate the costs and benefits of the relevant technology options as well as to determine which factors influenced usage of the technologies.

Stakeholder interviews

Some information differs only on regional or district level and was not included in the household survey. I have conducted several semi-structured and informal stakeholder interviews with local agro-input traders, agricultural extension officers, and IITA experts. I selected 10 agro-input traders in the field. These traders have been involved in the N2Africa programme and are aware of the relevant agricultural technologies. The interviews with the traders consisted of questions on input availability and prices, as well as some qualitative questions on the local input market in general. In addition, I conducted three informal interviews with (retired) agricultural extension officers to gather data on market prices of relevant legume crops, technical aspects of legume cropping (e.g. the time it takes to row space on hectare of land), and the usage of agricultural inputs in general. Last, I sent a query to an expert from the IITA with questions on the N2Africa project, agricultural technology adoption in Ghana, and associated challenges.

3.2.2 Secondary data

I use several secondary data sources. First, I conducted a literature review to construct the theoretical framework in Chapter 2. Second, to investigate usage patterns over time, I used existing data from the focal adaptation trials from 2015 and 2016. This includes detailed data on input usage, yield gains, and information on several socio-economic household characteristics of the target population. I have used this data to examine potential variation in usage over time and link this to specific household characteristics. I have used agronomic data from N2Africa field trials in Ghana to estimate yield gains resulting from the application of relevant agricultural inputs. I have used Geographic Information Systems (GIS) data to estimate distances to markets.

3.3 Empirical strategy and challenges

a. Empirical strategy. As discussed, my study consists of three parts: a descriptive analysis (Chapter 4), a CBA (Chapter 5), and an econometric analysis (Chapter 6). I discuss the methodology for each part at the beginning of the relevant chapter. I have organized and analysed my data with Excel, R, and STATA. First, I provide descriptive statistics in Chapter 4. This study is mainly explorative; a big aspect of it concerns the exploration and description of experiences from the field from an economic perspective. I have used the results of Chapter 4 to answer my first and second research question. Second, I construct a CBA regarding the usage of the relevant technologies. I have conducted the CBA to determine costs, benefits, and profitability associated with the relevant agricultural technologies. As such, I answered my third research question. Last, I have estimated several empirical models to explore which factors influence usage patterns within the targeted population. The results are organized in tables in Chapter 6. I used these results to answer my fourth research question.

b. Threats and challenges. Regarding the sampled population and data collection there have been several threats and challenges. First, there has been attrition within the targeted population. This means that not all of the targeted respondents of the focal adaptation trials in 2015 and 2016 could be relocated. In addition, my sample frame was limited due to the available data and due to participant selection. I only targeted farmers who had participated in the trials *and* of whom there was usable data. The interviewed farmers were therefore not sampled randomly from a larger target population. Farmers' participation in the focal adaptation trials was not assigned randomly. This restricts any conclusions drawn in this paper to apply only to farmers who have participated in similar trials, under similar conditions. The non-random assignment of the focal adaptation trials also implies that there is no control group – a group of farmers whom did not receive the project package. Any statistical results in this thesis (Chapter 6) are therefore not of a structural causal nature, but merely explorative and descriptive.

Second, there may be some measurement bias. I collected my data together with agricultural extension officers, some of whom were on familiar terms with the respondents. This could have affected the answers of the respondents. They may have answered in terms they think were desirable; or the question may have been misinterpreted or wrongly translated. Originally, I had included a willingness to pay module in the household survey, but due to misinterpretation the gathered data is not reliable. As a result, I neglect this module. The same goes for one risk preference question. I did not include the data related to these questions in the analysis. In addition, I did not organise any focus groups before beginning the main survey. To get a clear image of possible responses from farmers, this is something that would have been helpful. In addition, I did not include questions that probe for farmers' time preference. I argue that due to the limited time frame, I had to make certain choices and did not include it for that reason.

4 Data and Descriptive Statistics

In this chapter I will present my household- and market-level data and give corresponding descriptive statistics. Consequently, I will answer my first and second research questions. First, household level data provides information on which of the focal adaptation trial farmers from 2015 and 2016 have taken up (components of) the originally distributed agricultural technology options for grain legumes in 2017. In addition, I present relevant data from the same target population during- or in the seasons previous to the focal adaptation trials in 2015 and 2016, to compare usage patterns and characteristics over time. Second, I discuss the socioeconomic characteristics of these farmers in 2017. In addition, I partially answer my third research question by addressing the availability of the inputs on local markets in 2017 – understood here as a component of supply-side constraints associated with usage.

4.1 Household-level descriptive statistics

4.1.1 Socio-economic characteristics

To explore household characteristics and usage behaviour I use data that I gathered in 2017. As discussed, I revisited and interviewed 78 smallholder farmers who have participated in the adaptation trials in either 2015 or 2016. I collected data on farmers' household characteristics, input use and farm production, marketing, access to information, and risk preference.

Descriptive statistics are presented in table 4.1, which provides information on a number of standard household characteristics, such as gender, age, education, household size, and kinship, as well as on agricultural variables – land availability for cropping, and value of livestock owned – and on a set of socio-economic variables, such as the distance to the nearest market town, having food shortage at the beginning of the cropping season, access to credit and information, and risk preference.

To get an indication of farmers' (subjective) risk preference, three questions were posed based on simplified questionnaire elicitation methods (Charness, Gneezy, & Imas, 2013). These questions were:

(1) "Generally speaking, are you a person who is ready to take risks or are you trying to avoid risks?" (Scale of 1 to 5, where 1 implies that the farmer is completely risk avoiding, 3 is indifferent to risk, and 5 completely risk-taking.)

(2) "On a scale of 1 to 10, how would you assess your readiness to take risks when investing in agricultural inputs?"

(3) "If you had to choose between more food security with a small income increase and less food security with a big income increase, which would you pick?"

The third question was misinterpreted, and, consequently, I only use the first two questions. The calculation is as follows. Consider a farmer who answers, "I am indifferent about risk" at the first question and gives a 7 for his or her readiness to take risk at the second question. This farmer 'scores' a 2 for question one and a 6 for question two – for both scores 1 on the scale of the question is understood as 0, 2 as 1, and so on. I add up both scores, which makes for a score of 8. Consequently, the lowest possible score – completely risk averse – is 0 and the highest possible score – completely risk taking - is 13. Average risk preference scores are 7.79 in the Northern region and 8.05 in the Upper East region.

I proxy for access to agricultural information with the extension variable, which provides an indication of the number of visits by local agricultural extension services. In the Upper East region, 75 percent of the surveyed farmers was visited more than 3 times by an extension officer during the rainfall season. This was 95 percent in the Northern region.

Since I am interested in the effect of several economic determinants on usage behaviour, I give special attention to variables that serve as proxies for (transaction) costs and supply-side constraints. In Chapter 2 I mentioned that distance to the nearest market can serve as a reasonable first approximation of transaction costs (Binswanger & Rosenzweig, 1986 as cited in Omamo, 1998; Omamo, 1995 as cited in Omamo 1998). I mapped the distance to the nearest market town with GIS information using Google Maps. Most farmers indicated which market they visit to purchase inputs and sell crops. I linked this information with GIS data on the households' location to calculate the distance to the nearest market, taking into account motorable roads. In the Northern and Upper East regions, the average distance to the nearest market town is 9.4 and 8 kilometres, respectively. I use the variable food shortage in May – the beginning of the cropping season - as an indication of the availability of cash – or cash constraint. 23 percent of the surveyed farmers in the Northern region indicated that they experienced food shortage in May. This is 51 percent in the Upper East. The variables access to credit and membership of a farmer cooperative can serve as indicators for the risk-bearing capacity of farmers. For access to credit, I asked farmers if they were able to loan from an informal or formal source in 2017. Between 51 and 54 percent had access to formal or informal credit, while between 80 and a 100 percent of the farmers was member of a farmer cooperative.

4.1.2 Usage patterns in 2017

I summarize my data on usage patterns in table 4.2. I asked farmers which agricultural inputs they used on their legume crops in 2017. I chose the inputs based on the 2015 and 2016 focal adaptation trials. During these trials, all the surveyed farmers received a package with mineral fertilizer (TSP), inoculant (only for soybean packages), improved seed, and information on management practices – i.e. weeding and row planting. Regarding mineral fertilizer and improved seed, I analyse the usage of these inputs for legumes *in general.* This means that I do not specify which type of mineral fertilizer or improved seed was used and that usage of the unspecified types of mineral fertilizer and improved seed serve as proxies for usage of the N2Africa-promoted inputs. I am forced to do this because of the following reasons. First, in most cases, farmers said they used "NPK". However, since 'regular' NPK is not used on legume crops, the fertilizer that the relevant farmers used is probably YARA blend fertilizer, which is a type of NPK (4:18:18) supplemented with soluble CaO, MgO, B, and S, and a promoted alternative mineral fertilizer for legumes instead of TSP (Adjei-Nsiah, personal communication, April 17, 2018). However, farmers did not make this distinction during the interviews. The same goes for improved seed: in many cases farmers were not aware or did not remember the specific type of seed that they used, only whether it was considered 'improved' or 'local'.

Mean usage patterns for the inputs differed between the two regions as well as between the two legume crops. None of the groundnut farmers used mineral fertilizer on groundnut in the Northern region; only 5 percent of 22 farmers that produced groundnut did so in the Upper East region. These numbers are somewhat higher for soybean. In the Northern region, 14 percent of the 28 farmers who planted soybean applied mineral fertilizer to it. This was 62 percent of 26 farmers in the Upper East region. Improved seed was widely used, with averages above 60 percent in both regions. Most farmers who used improved seed had saved these from last season's harvest. Usage for row planting and weeding is very high, with a 100 percent usage of weeding for both crops. I do not specify how often farmers have weeded. This ranged from 1 to 3 times per season. Weeding and row planting are also practices that have been applied in years before the N2Africa project came along. The data does therefor not suggest that usage is due to the project.

Even though usage patterns of the promoted technologies are generally low, it is evident that there is a difference between the two regions. Why, for example, was usage of mineral fertilizer for soybean higher in the Upper East region compared to the Northern region? Based on experiences from the field (field note, November, 2017) and the data presented in table 4.1, there are (at least) two plausible reasons for this. First, the land available for cropping in 2017 was lower in the Upper East region. Population density is higher, but household size does not differ that much. This means farmers in the Upper East region have to produce the same amounts of food on less land. Agricultural intensification is a logical solution. Second, only farmers living in the Upper East region had access to MoFA mediated loans, and in this region not even in all three districts. As discussed in Chapter 1, I expect this loan to influence usage behaviour in the Upper East region and I analyse both factors in more detail in Chapter 6.

4.1.3 Qualitative responses for not using mineral fertilizer in 2017

Data in table 4.2 shows that usage levels are relatively homogenous, except for mineral fertilizer. This limits potential analyses on differences in usage levels to mineral fertilizer. For mineral fertilizer, there *is* an evident difference in usage between the two regions, as well as between soybean and groundnut. To better understand the reasoning behind decisions not to use mineral fertilizer on legume crops, I provide an overview of farmers' qualitative responses for *not* using mineral fertilizer on legume crops in table 4.3. I asked the farmers what their reason was for not applying mineral fertilizer to the legume crops they cultivated in 2017. For groundnut, 63 percent of non-using farmers said they had 'no money'. For soybean, this is 88 percent. Other reasons given differ from a lack of access or awareness to high prices of the inputs.

4.1.4 Usage patterns in 2015 and 2016

Investigating usage patterns of the focal adaptation trial farmers in previous years is necessary to get a broader understanding of usage behaviour over time. To illustrate, consider farmers who have used a specific type of mineral fertilizer in years previous to the adaptation trials: they have more experience with its application and are aware of potential benefits. The barrier to take up mineral fertilizer in subsequent years is lower for these farmers. Furthermore, farmers may have a history of investing cash in mineral fertilizer for their staple crops, but *not* for their legume crops. They make a choice to invest scarce financial resources in crops well known to them, crops that serve as their main source of food. Regrettably, I do not have information on usage patterns for staple crops in 2017, but data from the focal adaptation trials on usage behaviour can serve as a fitting alternative. Again, the specific type of NPK used is unspecified in this data and in the column 'own, control plot' (during the trial) the type of mineral fertilizer is unspecified altogether.

a. During the trials. I present data on usage behaviour of the targeted farmers in *the season(s) during and previous to* the focal adaptation trials in table 4.4. *During* the trials, farmers were asked to cultivate a 10x10m control plot, in addition to the 10x10 N2Africa trial plot. Here they were encouraged to plant the same legume as the trial plot, but with their own practices and inputs. Trial data serves as an indication of input use in the year of participation in the trial and is presented in the second column. Mineral fertilizer (unspecified type) usage was low for groundnut and soybean (3.9 and 5.9 percent, respectively). Weeding and row planting were widely practiced (75.3 and 95.3 percent, respectively). Again, it is important to note that these practices were widely used before the N2Africa project.

b. Season previous to trials. There are two sources of usage data for the season(s) *previous* to the focal adaptation trials. First, participating farmers were asked to record which crops they cultivated in the previous season on their largest field and their most important legume field. In addition, they were asked which inputs they used on these fields. Data in the fourth column of table 4.4 shows that the largest field was mostly used for the production of staple crops, such as maize, rice, sorghum and millet. Usage levels of mineral fertilizer (i.e. an unspecified type of NPK) on farmers' main fields was relatively high, especially for maize: roughly 89 percent of the farmers whom cultivated maize on this field applied an unspecified type of NPK to it. There is no data available on inoculant use one season before the focal adaptation trials. In addition, there is no data on seed variety names in the non-N2Africa fields in the season before the adaptation trials; there is only information on whether the seed used is improved (1) or local (0). Usage was quite low for both staple crops and legume crops, although, again, it was somewhat higher for maize (26.7 percent) and rice (33 percent), with the exception of groundnut (31.8 percent).

c. Season before previous season. In the final two columns of table 4.4 I present data on mineral fertilizer in *the season before the previous season* of the focal adaptation trials (two seasons before) – in 2013 or 2014, depending on the year of participation. Again, it is clear that usage of NPK for maize was high, with 89 percent of 38 farmers having applied fertilizer to maize. For sorghum and millet usage was low (10 and 11 percent, respectively). Usage of NPK for soybean and groundnut was zero, which makes sense if one considers that 'regular' NPK (15:15:15 or 23:10:5) is not used on legume crops. However, the type of NPK used is unspecified again. Out of 26 farmers, only 11.5 percent used inoculant. There is no data on (improved) seed usage or management practices for this time period.

Table 4.1 *Variable list and descriptive statistics*

	Northern				**Upper East**				**Total**			
	Mean	Std dev.	Min	Max	Mean	Std dev.	Min	Max	Mean	Std dev.	Min	Max
Gender of farmer (1 = male; 0 = female)	73 %	0.45	0.00	1.00	41 %	0.50	0.00	1.00	57 %	0.50	0.00	1.00
Gender of household head (1 = male; 0 = female)	97 %	0.16	0.00	1.00	95 %	0.22	0.00	1.00	96 %	0.20	0.00	1.00
Age (category) of household head (1 = 18-25, 2 = 25-50, 3 = 50-60, 4 = >60)	1: 2.63 % 2: 39.47 % 3: 23.68 % 4: 34.21 %	0.92	1.00	4.00	1: 0 % 2: 48.72 % 3: 23.08 % 4: 28.21 %	0.86	2.00	4.00	1: 1.3 % 2: 44.16 % 3: 23.38 % 4: 31.17 %	0.89	1.00	4.00
Maximum of primary education of household head, but no less (1 = true; 0 = other	16 %	0.37	0.00	1.00	18 %	0.39	0.00	1.00	17 %	0.38	0.00	1.00
Minimum of secondary education of household head (1 = true; 0 = otherwise)	27 %	0.45	0.00	1.00	8 %	0.27	0.00	1.00	17 %	0.38	0.00	1.00
Household size (number of members)	17.08	11.16	5.00	50.00	14.54	7.41	4.00	30.00	15.81	9.50	4.00	50.00
Children (number in household)	6.44	5.26	0.00	20.00	6.05	3.73	1.00	16.00	6.24	4.53	0.00	20.00
Relatives in community (1 = <10, 2 = 10-19, 3 = 20-29, 4 = >29)	1: 69.70 % 2: 15.15 % 3: 6.06 % 4: 9.09 %	0.97	1.00	4.00	1: 73.68 % 2: 7.89 % 3: 10.53 % 4: 7.89 %	0.98	1.00	4.00	1: 71.83 % 2: 11.27 % 3: 8.45 % 4: 8.45 %	0.97	1.00	4.00
Ratio of rooms per household members	0.44	0.16	0.19	0.91	0.54	0.26	0.20	1.09	0.49	0.22	0.19	1.09
Land available for cropping (in hectares)	5.67	5.37	0.00	24.30	3.46	2.46	0.81	12.15	4.56	4.30	0.00	24.30
Land rights (1 = household's own land; 0 = otherwise)	87 %	0.34	0.00	1.00	95 %	0.22	0.00	1.00	91 %	0.29	0.00	1.00
Value of livestock owned (in Tropical Livestock units)	2.54	3.95	0.00	20.60	4.91	5.71	0.00	20.80	3.72	5.02	0.00	20.80
Distance to market town (in kilometres)	9.39	4.23	0.50	23.50	8.01	5.57	0.50	18.00	8.68	4.98	0.50	23.50
Food shortage (in May 2017) (1 = true; 0 = otherwise)	23 %	0.43	0.00	1.00	51 %	0.51	0.00	1.00	37 %	0.49	0.00	1.00
Access to credit (1 = true; 0 = otherwise)	54 %	0.51	0.00	1.00	51 %	0.51	0.00	1.00	53 %	0.50	0.00	1.00
Household made use of MoFA mediated loan to purchase mineral fertilizer (1 = true; 0 = otherwise) *(Only for Upper East)*					38 %	0.49	0.00	1.00				
Farmer cooperative (1 = member; 0 = otherwise)	82 %	0.39	0.00	1.00	100 %	0.00	1.00	1.00	91 %	0.29	0.00	1.00
Visits by extension (1 = 1, 2 = 2, 3 = 3, 4 = >3)	1: 2.56 % 2: 2.56 % 3: 0 % 4: 94.87 %	0.57	1.00	4.00	1: 7.89 % 2: 5.26 % 3: 10.53 % 4: 76.32 %	0.92	1.00	4.00	1: 5.19 % 2: 3.9 % 3: 5.19 % 4: 85.71 %	0.78	1.00	4.00
Risk preference	7.79	3.49	1.00	12.00	8.05	2.84	4.00	11.00	7.92	3.17	1.00	12.00

Table 4.2 *Dichotomous usage choices of the technology options for (a) groundnut and (b) soybean (per region) in 2017*

a. groundnut	**Northern**		**Upper East**		**Total**	
Technology	Mean	N	Mean	N	Mean	N
Mineral fertilizer	0 %	33	5 %	22	2 %	55
(unspecified type of) "NPK"	0 %	33	5 %	22	2 %	55
TSP	0 %	33	0 %	22	0 %	55
Improved seed (any type)	94 %	33	68 %	22	84 %	55
Saved	52 %	33	55 %	22	53 %	55
Bought new	33 %	33	9 %	22	24 %	55
Row planting	82 %	33	100 %	22	89 %	55
Weeding	100 %	33	100 %	22	100 %	55
Intercropping	52 %	33	23 %	22	40 %	55

b. soybean	**Northern**		**Upper East**		**Total**	
Technology	Mean	N	Mean	N	Mean	N
Mineral fertilizer	14 %	28	62 %	26	37 %	54
(unspecified type of) "NPK"	4 %	28	62 %	26	31 %	54
TSP	11 %	28	0 %	26	6 %	54
Inoculant	11 %	28	4 %	26	7 %	54
Improved seed (any type)	96 %	28	73 %	26	85 %	54
Saved	64 %	28	35 %	26	50 %	54
Bought new	18 %	28	23 %	26	20 %	54
Row planting	86 %	28	100 %	26	93 %	54
Weeding	100 %	28	100 %	26	100 %	54
Intercropping	11 %	28	46 %	26	28 %	54

Table 4.3 *Qualitative responses for not using mineral fertilizer on (a) groundnut and (b) soybean in 2017*

a. groundnut			**b. soybean**		
Response	N	Percent	Response	N	Percent
NA	10	21.74	NA	1	2.94
High price of input	1	2.17	High price of input	1	2.94
Groundnut does not respond	1	2.17	No money	30	88.24
No access	3	6.52	Not aware of its use	1	2.94
No money	29	63.04	Not necessary	1	2.94
Not aware of its use	1	2.17			
Used it last year	1	2.17	Total	34	100.00
Total	46	100.00			

Table 4.4 *Dichotomous usage choices of the focal adaptation trial farmers' seasons during and before the focal adaptation trials in 2015 and 2016*

Input	Own, control plot[6] (trial)	N	Largest field	N	Most important legume field	N	Season before previous season	N
Mineral fertilizer								
Maize		0	88.5 %	52		0	42.1 %	38
Millet		0	0 %	4		0	0 %	8
Rice		0	33.3 %	3		0		0
Sorghum		0	0 %	4		0	10 %	10
Soybean	5.9 %	34	27.3 %	11	0 %	20	35.3 %	17
Groundnut	3.9 %	26	0 %	3	7.1 %	14	41.7 %	12
Cowpea		0		0	0 %	6	0 %	1
Pigeon pea		0		0	0 %	1		0
Bambara bean		0		0	0	0	0 %	3
Sweet potato		0		0	0	0	0 %	1
Other, unspecified	0 %	46						
Inoculant (for soybean)	0 %	34					11.5 %	26
Improved seed (vs local)								
Maize			26.7 %	60		0		
Millet			0 %	5		0		
Rice			33 %	3		0		
Sorghum			0 %	6		0		
Soybean			0 %	15	3.4 %	59		
Groundnut			0 %	3	31.8 %	22		
Cowpea				0	6.7 %	15		
Pigeon pea				0	0 %	1		
Bought seed (vs saved)								
Maize			22 %	59		0		
Millet			0 %	5		0		
Rice			0 %	3		0		
Sorghum			0 %	6		0		
Soybean			0 %	15	15.3 %	59		
Groundnut			0 %	3	30 %	20		
Cowpea				0	57.1 %	14		
Pigeon pea				0	0 %	1		
Management practices								
Weeding	95.3 %	106						
Row planting	75.3 %	105						
Intercropping	1.9 %	104						

Season of trial: 'Own, control plot' column; season before trial: 'Largest field' and 'most important legume field' columns; two seasons before trial: 'Season before previous season.' Column. The 'own, control plot' and 'two seasons before trial' plots are not necessarily the same as the 'largest field' or the 'most important legume field'.

4.1.5 Comparing usage behaviour of the focal adaptation trial farmers over time

When comparing the data in table 4.2 with the data in table 4.4, there seems to be a consistent pattern in usage over time. Three things spring forward. First, usage levels of mineral fertilizer have been high in the years previous to the focal adaptation trials. This suggests that farmers *do* have cash available at the beginning of the season to invest in agricultural technologies, such as mineral fertilizer. Nevertheless, the cash constraint that farmers mentioned as their reason for not purchasing mineral fertilizer for their legume crops may still hold. Either legume crops are (perceived to be) unprofitable, or the farmers only have enough cash to invest in a limited amount of technologies. Other reasons, then, lead farmers to buy inputs for either their staple crops or for their legume crops.

[6] Fertilizer type is *not* specified in this data.

Staple crops are known for a much longer time and are farmers' main source of food (field note, November, 2017). Second, legume crops are only slowly beginning to be culturally accepted. For example, there may be some gender differences in deciding whether or not to use legume crops for consumption (Kerr, Snapp, Chirwa, Shumba, & Msachi, 2007).

Second, farmers saved seed more often than purchasing it new, except for cowpea. If, as hypothesized, farmers are subject to cash constraints that form a barrier to input usage, saving seed is financially preferred to buying new seed. This finding is in line with my 2017 usage data in table 4.2. In addition, usage of local seed was somewhat higher as compared to usage of improved seed, which may imply that improved seed is more expensive or that it is unavailable on the market. Both this cash constraint and supply-side constraint are plausible explanations for low usage behaviour. I will analyse and discuss the plausibility of both constraints in more detail in the subsequent chapters.

Third, usage of the management practices is high, except for intercropping. Only 1.9 percent of 104 farmers intercropped on their own control field during the focal adaptation trials. Weeding and row planting was high, which is in line with my 2017 usage data, presented in table 4.2. Interestingly, the costs of weeding and row planting are significantly lower than mineral fertilizer and bought seed and these are practices that were already performed many years before the project. I present and discuss the costs associated with the agricultural technologies in Chapter 5.

In table 4.5a and 4.5b I present cross-tabulations of usage behaviour over time. When comparing usage patterns in the years previous and during the focal adaptation trials with usage in 2017 it becomes clear that only a very small percentage of the farmers 'continually' used either mineral fertilizer or purchased improved seed. For example, only 2.5 percent of the farmers who applied mineral fertilizer on groundnut on their largest field in the year previous to the trials also applied it to groundnut in 2017; while 47.50 percent used it on this field, but did not apply it again in 2017. For soybean this is somewhat higher: 33.33 percent. Regarding purchased seeds, only 4.08 percent of the farmers bought improved soybean seed in 2017 as well as in the year before their participation in the trials. There is no information on bought seed usage during the trials.

There are two interesting points that become evident from tables 4.5a and 4.5b. First, the results substantiate the argument by Ronner et al. (2017) that farmers make their *usage* decision separately each consecutive year – opposed to *adopting* a technology for the foreseeable future. Ronner et al. explain that, when a project promotes highly specialized sets of options, they are only targeting a small percentage of the farmers – only those that will take up the whole set of options. The data presented in table 4.5a and 4.5b leads me to draw a similar conclusion: farmers adapt the inputs they receive to their personal circumstances. Second, and perhaps contradictory to the latter argument, non-usage seems to be more consistent. The percentage of farmers who did *not* take up fertilizer or bought seeds in 2017 and preceding years is relatively higher to those that did use it. In the next chapter I will categorize the inputs into cost-categories and make a comparison with usage patterns. Here I show how 'high-cost' inputs have relatively low usage compared to 'low-cost' inputs.

Table 4.5a *Comparison of mineral fertilizer usage of the trial farmers over time for (a) groundnut and (b) soybean*

a. Usage mineral fertilizer	Usage in 2017 (in percent)		
Trials own field (during trial)	0	1	Total
0	96.36	1.82	98.18
1	1.82	0.00	1.82
Total	98.18	1.82	100.00
Largest field (before trial)	0	1	Total
0	50.00	0.00	50.00
1	47.50	2.50	50.00
Total	97.50	2.50	100.00
Most important legume field (before trial)	0	1	Total
0	95.45	0.00	95.45
1	4.55	0.00	4.55
Total	100.00	0.00	100.00

b. Usage mineral fertilizer	Usage in 2017 (in percent)		
Trials own field (during trial)	0	1	Total
0	61.11	37.04	98.15
1	1.85	0.00	1.85
Total	62.96	37.04	100.00
Largest field (before trial)	0	1	Total
0	30.77	7.69	38.46
1	28.21	33.33	61.54
Total	58.97	41.03	100.00
Most important legume field (before trial)	0	1	Total
0	77.78	22.22	100.00
1	0.00	0.00	0.00
Total	77.78	22.22	100.00

Table 4.5b *Comparison of bought seed usage of the trial farmers over time for (a) groundnut and (b) soybean*

a. Usage mineral fertilizer	Usage in 2017 (in percent)		
Largest field before trials	0	1	Total
0	71.15	19.23	90.38
1	9.62	0.00	9.62
Total	80.77	19.23	100.00
Most important legume field before trials	0	1	Total
0	65.31	20.41	85.71
1	14.29	0.00	14.29
Total	79.59	20.41	100.00

b. Usage mineral fertilizer	Usage in 2017 (in percent)		
Largest field before trials	0	1	Total
0	76.00	14.00	90.00
1	10.00	0.00	10.00
Total	86.00	14.00	100.00
Most important legume field before trials	0	1	Total
0	69.39	12.24	81.63
1	14.29	4.08	18.37
Total	83.67	16.33	100.00

Table 4.6 *Input availability on local markets in 2017*

	Northern		**Upper East**		**Total**	
Input	Mean	N	Mean	N	Mean	N
Mineral fertilizer						
TSP	0 %	4	0 %	6	0 %	10
NPK[7]	50 %	4	100 %	6	80 %	10
SSP	0 %	4	0 %	6	0 %	10
DAP	0 %	4	0 %	6	0 %	10
UREA	50 %	4	100 %	6	80 %	10
YARA blend	25 %	4	50 %	6	40 %	10
Inoculant	0 %	4	0 %	6	0 %	10
Seed						
local groundnut	0 %	4	17 %	6	10 %	10
Samnut 23	0 %	4	0 %	6	0 %	10
Samnut 22	0 %	4	0 %	6	0 %	10
Sari Chinese	0 %	4	0 %	6	0 %	10
TGX	0 %	4	0 %	6	0 %	10
local soybean	0 %	4	17 %	6	10 %	10
Jenguma	25 %	4	0 %	6	10 %	10
Afayak	25 %	4	0 %	6	10 %	10

[7] 15:15:15 or 23:10:5.

4.2 Market-level descriptive statistics: input availability in 2017

In this section, I present my market-level data. During the implementation of my household survey I asked farmers which market they visit to purchase agricultural inputs. Taking into consideration farmers' answers to this question, I visited the main, local markets and interviewed two agro-input traders in each district. I asked the traders which inputs they had available during the rainfall season in 2017. I present this data in table 4.6.

The data clearly shows that there is a lack in supply of many of the promoted inputs. TSP fertilizer, for example, was widely unavailable, while this is one of the mineral fertilizers that was distributed in the focal adaptation trials. Inoculant was also unavailable, mainly due to lack of proper storage facilities, even though traders expressed their awareness of the demand for inoculant by farmers (field note, November, 2017). Improved seed was mostly unavailable because there are no (certified) seed growers that produce improved seed in large enough quantities (field note, November, 2017). There seems to be no apparent difference in input availability between the two regions. The availability of NPK (15:15:15 and 23:10:5), UREA, and YARA blend fertilizers is somewhat higher in the Upper East. Due to the limited amount of observations, however, I am unable to make significant conclusions about the extent of availability of the latter fertilizers.

4.3 Concluding remarks

In this chapter, I presented farmers' 2017 usage patterns of a set of technologies that were promoted and disseminated in the 2015 or 2016 focal adaptation trials. In addition, I gave socio-economic household characteristics of these farmers. Data shows that usage of several of the promoted inputs is low. Incidental or not, these are inputs that have to be bought on the local market. Market level data shows that some of these inputs, such as TSP and inoculant, are unavailable on the local markets. One line of reasoning is that low usage is due to a lack of availability. Especially for inoculant, which is a relatively cheap input (discussed in chapter 5), this may be a plausible reason. For mineral fertilizer, however, this does not have to be the case. Alternative kinds of mineral fertilizer, such as various types of NPK - i.e. 15:15:15, 23:10:5, and YARA blend are available. The YARA blend fertilizer can be used on legume crops. Farmers said that low usage of mineral fertilizer for legumes is often due to lack of money to purchase it. This begs the question whether the subjective 'no money' reasoning is a valid explanation for low usage of mineral fertilizer. The profitability and cash-flow of usage is discussed in more detail in Chapter 5.

To conclude, it may be asked what criteria I used in deciding which variables to include or omit. The first was the relevance of most of the variables in the academic literature discussed in Chapter 2. The second criterion was the overlap with existing focal adaptation trial data. In addition, it is important to consider some limitations of the data I presented and the conclusions I draw from it. I present usage patterns of weeding and row planting. These practices are, however, already used many years before the N2Africa project came along and one should therefore not read the statistics as if high usage of these practices is a result of project participation. I also do not include information on how many times a farmer weeded or what the spacing was between their rows (when planting in rows). The recommended amount of weeding by the project was three times per season and usage patterns in table 4.2 may have been different if I had taken this into account. The input availability presented in table 4.6 is also not a good representation of input availability in the region. The sample of traders was small, picked non-randomly, not evenly distributed between the two regions. One should therefor interpret the results with caution.

5 Cost-Benefit Analysis

In this chapter I will assess the profitability of a concrete set of promoted agricultural technologies for grain legumes and (partially) answer my third research question. I assess the costs and benefits that are associated with usage of relevant technologies in northern Ghana and I estimate the profitability of specified sets of technologies in two production- and marketing settings. An analysis of the profitability of the promoted agricultural technologies is needed to better understand farmers' usage behaviour and the reasoning behind their choices.

This chapter proceeds as follows. First, I present my method and relevant cost- and price data. I sort the technologies into two cost categories: low-cost- and high-cost inputs. Second, I provide a CBA that I use to determine the profitability of (a set of) the technologies under specified conditions. In advance I note that, owing to the high heterogeneity of costs and benefits that are associated with input usage, the analysis provided in this chapter can only serve as a limited resemblance of reality; and it only serves to illustrate what *may* be the case for farmers in several situations.

5.1 Data and methodology

5.1.1 Method

To estimate profitability (P) of input usage, the total measurable costs of usage will be deducted from the additional revenue:

(1) $$P = AR - (AC + MC)$$

Where AR is the revenue from additional grain yield in US\$/ha^{-1} and is captured as the additional market value of production when concrete technology options are used. AC is the total cost of taking up the concrete technology options in US\$/ha^{-1}. For the total cost of taking up concrete technology options I consider labour costs, input purchasing costs, opportunity costs, and transportation costs, which may occur at various levels. MC is the total cost of marketing the additional grain yield in US\$/ha^{-1}. Costs of marketing the crop include transportation costs, labour costs, and opportunity costs. If P is greater than zero, technology usage is assumed to be profitable and usage of the concrete technology options is considered a rational decision. For the sake of the present study, the production setting with the highest calculated P should, theoretically, have the highest usage ratio. Nevertheless, since I deal with heterogeneous costs, there is no one-size-fits-all production setting that is most desirable.

5.1.2 Cost- and price data

I present the costs and prices that are associated with usage of the relevant agricultural technologies in tables 5.1 and 5.2. Costs and prices are obtained through stakeholder- and farmer interviews. All monetary values are deflated to the 2017 average exchange rate[8] and converted to US$ for convenience. *Costs* in this study are understood as those costs related to the usage of agricultural inputs. Broadly, these include input-, labour-, opportunity-, and transaction costs. Note that there exists considerable heterogeneity among farms in terms of usage costs (Suri, 2011). In addition, since I focus only on the costs related to input usage, my definitions of costs exclude several costs related to 'overall' agricultural production, such as the costs of renting land, ploughing, harrowing/levelling, and depreciation (of e.g. hoes, cutlasses, and sacks). I argue that the farmer makes these costs

[8] GHS/USD at 0.225 (XE Currency Charts, 2017)

regardless of the inputs he or she utilizes. The same can be said for several labour costs, such as land clearing, planting, harvesting, threshing, and drying and winnowing. However, since additional grain yields are expected to be higher due to input implementation, time spent harvesting, threshing, and drying and winnowing may increase, although I expect this change to be marginal. I therefor neglect this possibility.

Concerning *prices*, not all traders had the same inputs available in 2017, but I expect the prices to be fairly homogenous among the five districts. Where possible, I take average prices between the districts. I differentiate between market- and farm-gate prices – or, consumer- and producer prices, respectively, according to the Low Farm Household Model (Ellis, 1988). For soybean, the farm-gate price is 0.32 US$/kilogram and the market price is 1.20 US$ per kilogram. For groundnut, the farm-gate price is 0.27 US$/kilogram and the market price is 1.25 US$ per kilogram. The prices were given by agricultural extension officers during interviews (field notes, October-November, 2018) and by visiting local markets. In what follows, I give several examples of my calculations.

I derive labour costs per day by taking the average casual on-farm wage that is paid in the districts. Farmers pay labourers around 2 dollars a day for 12 hours of work. I also use this cost as the opportunity cost of time; hypothetically, every day a farmer does something he could have been working on somebody else's farm for 1.99 US$. My calculation of transportation costs is also based on information received from farmers. I asked several farmers how much they pay to take a Motor King[9] to town. Transportation costs depend on the amount (in kg) that needs to be transported and the time/distance. 9 US$ is the maximum; a farmer can fill the whole motor king and get transported for about an hour for this price. I calculated a kg/hour price of 0.05 US$, with a maximum of 9 US$/hour.

To illustrate, consider a farmer who lives 30 minutes (by Motor King) from the nearest market town. This farmer wants to purchase and apply the recommended amount of YARA blend for one hectare (247.5 kilograms). First, he needs to travel an hour, which results in opportunity costs of transport (in time) of (1.99 US$/12 =) 0.17 US$. In addition, the farmer needs about two days to fertilize an acre, which costs him 1.99*2= 3.98 US$/acre^{-1} in opportunity costs. Converted to hectares, this is 9.85 US$/ha^{-1}. This totals to 10.02 US$/ha^{-1} in opportunity costs alone. I do not include labour costs of applying the fertilizer; for this case, I assume the farmer will only use household labour. Second, the farmer has to pay for transportation. Transporting roughly 250 kilograms of YARA blend will cost about 12.5 US$. The maximum, however, is set at 9 US$/hour. Third, the farmer has to purchase the YARA blend on the market, which, depending on whether the price is subsidized or not, costs 77.16 US$/ha^{-1} or 119.74 US$/ha^{-1}, respectively. In total, the farmer will need *at least* 96.18 US$/ha^{-1} to purchase and apply the recommended amount of YARA blend for one hectare.

I face several limitations regarding costs and prices. First, the local prices of some types of seed (e.g. Samnut 22 and 23) and fertilizer (e.g. TSP) are unknown to me. These inputs were unavailable at any of the local agro-input traders that were visited. Consequently, I base the cost categories on prices of substitute types of seed (local seed, which may also be improved seed from before the start of the N2Africa project) and mineral fertilizer (YARA

[9] A motorized tri-cycle, widely used in northern Ghana to transport goods and people.

blend). Since TSP was unavailable on the local markets, YARA blend has been the most suitable alternative[10]. The costs of the *promoted inputs* (in 2015 or 2016) therefor differ in reality. I allow myself to make these substitutes considering my aim is to explain usage behaviour of the farmers in 2017. Since the farmers were only able to purchase and use the substitutes, I argue that the given prices resemble reality more closely. Second, in many cases I was unable to get information on the same type of costs in all the five districts. In reality, however, costs differ between region and district, and often even between communities. In addition, as I discussed in Chapter 2, not all costs and benefits are observable or measurable in monetary terms. Even if they are observable, mapping these costs would have required additional data collection.

Table 5.1 *Variable list costs and benefits*

Variables	Definition
Profitability (P)	P = A R – (AC + MC)
Benefits (A R)	(Estimations of) additional grain yield in US$/ha^{-1} resulting from usage of input package
Costs (A C; M C)	
Labour costs	Hired labour per hectare (in adult days) x on-farm wage factor (1.99 US$).
Input costs	The market/consumer price (US$) of the inputs x amount (kg) (to be) used per hectare.
Opportunity costs	1. Labour per hectare (in adult days) and time spent on transport (in adult days) x 1.99 US$ (casual labour price in US$day^{-1}) 2. On-farm consumption, or the income that could have been earned when selling produce that is consumed. Calculated as the amount (in kilograms) consumed x a farm-gate price
Transportation costs	Distance to a market (km) x factor-price (0.05 US$) per kilometre

Table 5.2 *Costs of usage of the relevant technologies (in US$/ha^{-1})*

Input	**Input costs**	**(+)**	**Transaction costs**	**(+)**	**Opportunity costs**	**(=)**	**Total**	**Cost Category**
Inoculant	3.76		0.11		5.09		8.96	Low
Fertilizer								
YARA blend (247kg)	119.74		9.00		10.02		138.76	High
Subsidized YARA blend (247kg)	77.16		9.00		10.02		96.18	High
Seed								
New local groundnut (123.8kg)	111.39		5.57		0.17		117.13	High
New local soybean (44.5kg)	20.05		2.00		0.17		22.22	Low
Saved local groundnut	0.00		0.00		33.42		33.42	Low
Saved local soybean	0.00		0.00		14.03		14.03	Low
Management practices								
Weeding (once)	0.00		0.00		24.63		24.63	Low
Row planting	0.00		0.00		24.63		24.63	Low

Low-cost category: <50 US$/ha^{-1}. High-cost category: =>50 US$/ha^{-1}.

[10] YARA blend is NPK 4:18:18 plus 14 percent soluble CaO, 2 percent MgO, 0.3 percent B, 2 percent S and has been widely promoted in 2017 (Adjei-Nsiah, personal communication, April 17, 2018).

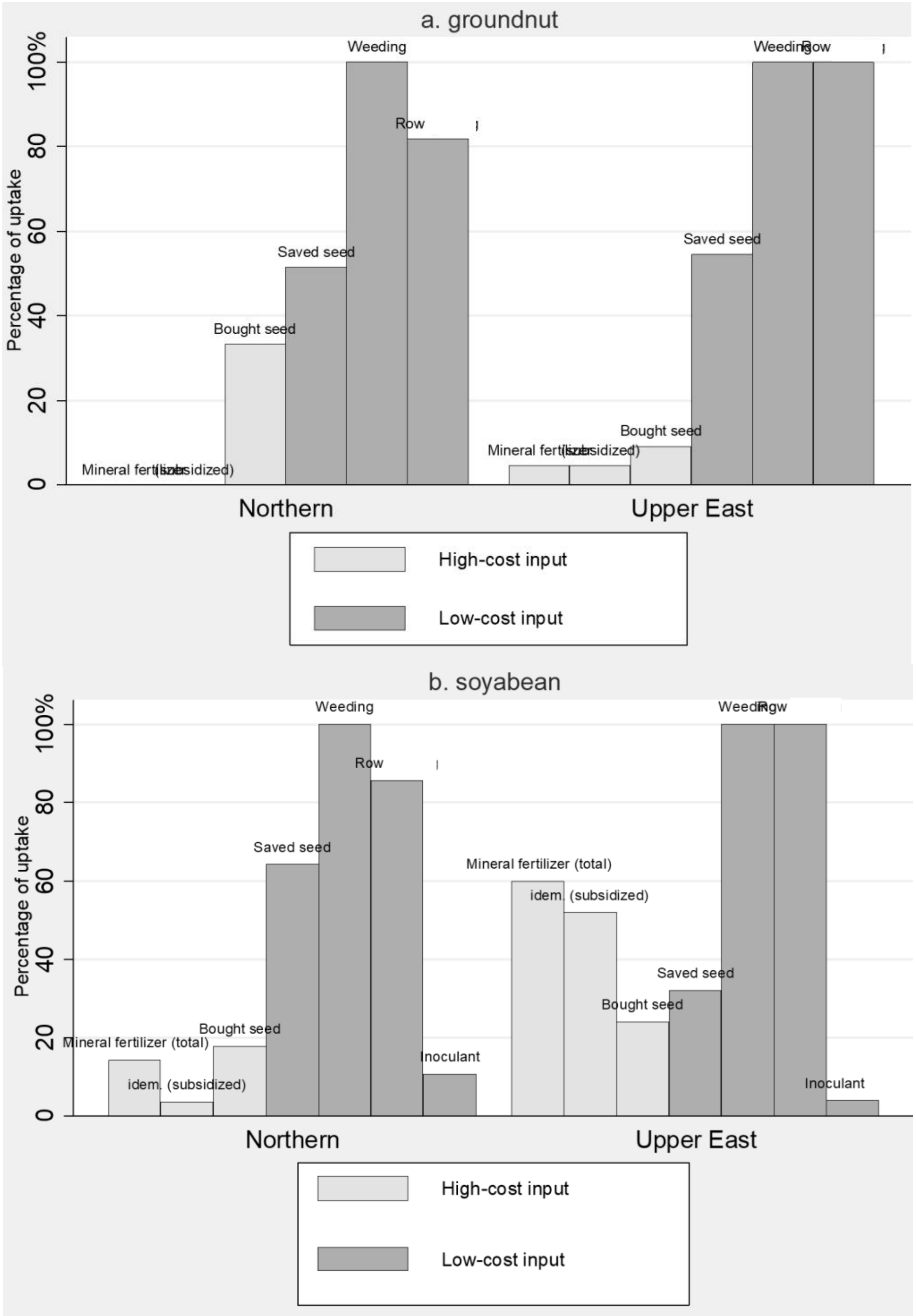

Figure 5.1 *Low- and high-cost categorization and correlation with usage patterns for (a) groundnut and (b) soybean*

5.1.3 Cost categories

The results in table 5.2 clearly show how some of the agricultural technologies require a much higher investment in US$/ha^{-1}. I have arbitrarily set 50 US$/ha^{-1} as a threshold and I divided the technologies into two categories. I present these categories in the last column. Most of the technologies that have to be purchased on the market, except for inoculant and new local soybean seed, fall into the high-cost category. I present the usage ratios of the inputs in the regions in figure 5.1, taking into consideration the cost category of each input. Except for inoculant, low-cost inputs have relatively high levels of usage. The comparison between saved seed and bought seed is most interesting. The figure shows how uptake of saved seed is much higher as compared to bought seed. Bought seed is also a much more expensive input. Uptake of weeding and row planting is also high and I calculated their costs to be low. Comparing these practices with other inputs, however, must be done with caution. Weeding and row planting are practices that have been used for many years and can therefore not be compared to *new* inputs promoted by the N2Africa project. Considering inoculant, I argue that its costliness is unlikely to explain low usage rates; a lack of availability and awareness are reasonable alternative explanations. For the other inputs, however, there is a correlation between costs and usage. Mineral fertilizer usage for soybean is relatively high in the Upper East region, but otherwise it is low, even when separating the farmers who made use of the government subsidy. Farmers more often save seed than purchase it anew, which is in line with the fact that saving seed is generally cheaper.

5.2 Cost-Benefit Analysis

5.2.1 Profitability of a full technology package

Within the bounds of this study, it is impossible to assess the profitability of input usage for each separate farmer. There are many heterogeneous factors that influence the costs and benefits that will eventually determine profitability. In the following paragraphs, I therefore estimate the profitability of concrete technology options for soybean in several specified *settings*. I do not estimate the profitability for groundnut because I lack the grain yield data that is needed to estimate additional revenue from usage of the relevant technologies.

a. Setting and investment required. The given situations are based on a number of usage orientations, such as whether or not a farmer makes use of the government subsidy on mineral fertilizer or saves seed instead of purchasing it new. The investments that are required depend on the usage orientation of the farmer and are presented in table 5.4 under the column *investment required.* Second, I use two production orientations that are mainly derived using information from the household survey. I asked farmers how much of their legume crops they normally sell and/or consume. I present the related responses in table 5.3. Most farmers indicated that they sold most of their legume crops to an aggregator or on the local fresh produce market. Consequently, in the first orientation, I assume that the farmer sells 50 percent of the additional grain yield (per hectare) to a trader at a producer price and 25 percent on the local market at a consumer price, while keeping 25 percent for subsistence consumption. In the second orientation, I assume that the farmer sells 25 percent of the additional grain yield to a trader and 25 percent on the local market for a relatively higher market/consumer price, while keeping 50 percent for subsistence consumption.

b. Subsistence consumption. There are two ways to value subsistence consumption. First, one can assume that a household will not reduce its consumption when there is reduced subsistence production. This implies that the household will purchase food if there is a production deficit, as long as it substitutes the same crop that would have been produced (Groeneveld, personal communication, March 29, 2018). As such, subsistence consumption can be calculated as a *benefit* by multiplying the amount (in kg) consumed with the consumer price (Kategile et al., 1987). Second, one can consider the amount of additional grain yield that is consumed on-farm as an opportunity costs, since it could have been sold on the market, depending on the level of integration of the household in the market economy (Ellis, 1988). Because I am interested in the effect of financial constraints on usage behaviour, there is a strong argument in favour of using the latter valuation method. Foremost, because selling crops reduces farmers' cash constraints; second, because I can assume the farmers are integrated into the market economy and are therefore able to sell surplus production. The latter argument is valid because farmers indicated they sell most of their legume crops (table 5.3) and because they purchase inputs on the local market (Chapter 4).

c. Additional grain yield- and revenue. Additional grain yield, representing farmers' benefits from usage, is another factor that may differ significantly between farmers or between districts. Using a simple mixed model in STATA, I predict the additional grain yield gained from applying relevant agricultural technologies based on data N2Africa's 2017 focal adaptation trials. The model is as follows:

(1) $$Y_i = \beta_{cons} + X_i \beta_{inputs} + \alpha_i + \varepsilon_{i.}$$

Where Yi represents the grain yield corresponding to usage of a given input per household i. βcons is the vector of the constant. Xi are the inputs used by household i. βinputs is the corresponding coefficient. αi represent district-specific random effects. εi is a household specific error term.

The predicted grain yield of the farmers' control plots, without usage of any of the promoted inputs, is subtracted from the predicted grain yield of farmers' N2Africa plots, which considers usage of (combinations of) technologies – i.e. YARA blend, inoculant, (any type of) improved seed, row planting, and weeding. For soybean, the predicted yield for the control plot is 968.98 kg per hectare; the predicted grain yield for the full-usage N2Africa plot is 1534.69 kg per hectare. This results in a predicted *additional* grain yield of 565.72 kg per hectare. In a setting in which a farmer does not apply YARA blend, but does apply inoculant, improved seed, and relevant management practices the predicted grain yield is 1362.92 kg per hectare. This results in a predicted additional grain yield of 393.95 kg per hectare. When one leaves out both inoculant and YARA blend, the predicted additional grain yield becomes 222.17 kg per hectare. I use the latter two predicted yields in section 5.2.3 to assess the profitability of several adaptation settings. As mentioned, I lack sufficient data to calculate the additional grain yield for groundnut.

Revenue from the additional grain yield is calculated as the value of cash sales minus the value of subsistence consumption. I present revenues in the *additional revenue* columns in table 5.4. In reality, saved seed and bought seed can both affect additional grain yield differently. I exclude possible yield differences resulting from seed types, because I lack the required data.

d. Marketing costs. In addition, additional grain yield, when sold, increases marketing costs. I present these under the columns *costs marketing* in table 5.4. Marketing costs consist of labour- and transportation costs. For example, I include labour costs of selling produce when a farmer personally sells additional yield at the local fresh produce market. I assume there are 12 hours in a working day and I arbitrarily take it that a farmer can sell 2 kg per hour. In this particular setting, it will take this particular farmer 5.89 days to sell 141.43 kilograms of produce (the 25 percent that the farmer has to sell on the local fresh produce market in both production orientations). Selling this amount in such a time frame may not be possible in reality; it may take longer. Nevertheless, I make this assumption for the sake of the argument. As a result, labour costs (understood here as opportunity costs) are 1.99 US$ * 5.89 = 11.72 US$. When adding transportation costs - 9 dollars, the total cost of marketing for both production orientations in table 5.4 becomes 20.72 US$ per hectare.

e. Profit. I present the profitability estimates in the *profit* columns in table 5.4. I have calculated the net present value[11] of usage using a discount rate of 12.1 percent[12]. This value gives the worth of investment at the beginning of the rainfall season – when a farmer has to make the decision to invest or not. Strikingly, all combinations of usage- and production orientations, except for one, are unprofitable. The sole example of a profitable setting is the following. A soybean farmer who is to use subsidized YARA blend fertilizer and who saved seed from last year's harvest would have to invest 193.09 US$ per hectare, which includes transportation- and opportunity costs. Selling 75 percent of the additional grain yield, while consuming 25 percent, would give an additional revenue of 214.27 US$/ha^{-1}. Subtracting 20.72 US$ in costs of marketing the crop, the farmer would face a small discounted profit of 0.13 US$/ha^{-1}, which is negligible, to say the least.

5.2.2 Linking profitability to usage behaviour in 2017

Based on the profitability estimations presented in table 5.4, one can expect usage of subsidized fertilizer in combination with either saved or bought seed for soybean to be highest. Looking at figure 5.1, usage of subsidized fertilizer is in two of the four cases higher than non-subsidized fertilizer. For example, 62 percent of the farmers purchased fertilizer for soybean in the Upper East region. Around 55 percent of the farmers purchased it with the subsidy, meaning that only 7 percent of the farmers did *not* use the subsidy. This finding substantiates the profitability results, assuming farmers will rather choose a technology package that is profitable rather than one that is not.

There is one contradiction worth mentioning. Even when I predict usage of the used technology packages to be unprofitable in most cases, there has been some usage – i.e. of mineral fertilizer for groundnut and improved purchased seed for soybean and groundnut. This can have two reasons. First, profitability is highly context-dependent, meaning that my CBA applies only to farmers under specific circumstances. For other farmers it may have been profitable or they thought it would be - subjective expectations of the benefits of usage may be higher than economic expectations. Second, farmers adapted the packages in order to include only those components that they consider to be worthwhile to implement. I will address this in the next section.

Table 5.3 *Production orientation of legume crops for (a) groundnut and (b) soybean farmers*

	Groundnut		**Soybean**	
	Freq.	Percent	Freq.	Percent
"All consumed"	0	0	3	6
"Most consumed"	10	18	7	13
"Half consumed/half sold"	12	22	11	20
"Most sold"	32	58	32	59
"All sold"	1	2	1	2

[11] Present value = amount of money (in 6 months) x PVF (Present Value Factor). PVF = 1 / $(1+r)^n$ = 0.276289482

[12] Average inflation rate in Ghana in 2017 (Trading Economics, 2018).

Table 5.4 *Cost-Benefit Analysis: Full package usage settings for soybean (in US$/ha^{-1})*

Usage orientation	**Investment required**	**Production orientation 1**			**Production orientation 2**		
		Add. revenue	Costs marketing	Total Net Present Profit	Add. revenue	Costs marketing	Total Net Present Profit
Soybean							
No subsidy on fertilizer; inoculant; bought seed	243.86	214.27	20.72	-13.90	125.17	20.72	-38.52
Subsidy on fertilizer; inoculant; bought seed	201.27	214.27	20.72	-2.14	125.17	20.72	-26.75
No subsidy on fertilizer; inoculant; saved seed	235.67	214.27	20.72	-11.64	125.17	20.72	-36.26
Subsidy on fertilizer; inoculant; saved seed	193.09	214.27	20.72	0.13	125.17	20.72	-24.49

Production orientation 1 = 50 percent of crop sold to trader, 25 percent sold on local market, 25 percent kept for own consumption; Production orientation 2 = 25 percent of crop sold to trader, 25 percent sold on local market, 50 percent kept for own consumption. Output prices (US$/kg): soybean farm-gate/producer = 0.32 market/consumer = 1.20.

5.2.3 Profitability of an adapted technology package

As I mentioned, there appears to be a clear link between the costliness of several inputs – labelled as high-cost inputs - and low usage levels. This begs the question of how a CBA will look if one leaves out (several of) the package components. Would usage be profitable if a farmer does *not* apply YARA blend mineral fertilizer, but does apply improved seed and relevant management practices? The investment requirements would be much lower, but so, too, will additional revenue. Taking into account the downward shift in both additional revenue as well as the costs of usage, I analyse the profitability of several adapted packages for soybean in table 5.5. Again, I possess the data that is required to sketch situations for soybean where both inoculant and mineral fertilizer are left out, or where only mineral fertilizer is left out. Regrettably, there is no reliable grain yield data to assess similar situations for groundnut. I uphold a similar structure as in table 5.4, presenting four adaptation settings under the same two production orientations. First, I consider two situations in which a farmer does not purchase YARA blend and inoculant and either saved his or her seed from previous season's harvest or bought it new. Second, I consider two settings in which a farmer does not purchase YARA blend but buys inoculant and either saves seed or buys it anew on the market.

The results presented in table 5.5 show that the investment required for each adaptation setting is much lower. But so is the additional revenue that is generated. There are two settings where there is a small profit margin. This is when a farmer uses inoculant in combination with either bought or saved seed and the general management practices, and sells 75 percent of his or her additional crop – i.e. under production orientation 1. This farmer could make a discounted profit between 7.59$ and 9.85$. Contrariwise, when a farmer saves improved seed from last year's harvest and does not purchase inoculant or fertilizer, he or she would, under production orientation 1, make a discounted loss of 4.31 US$/ha. In production orientation 2, where the emphasis is on consumption, expected losses are higher, because I value subsistence consumption as an opportunity cost. In all cases it pays to take up inoculant. As mentioned in section 5.1.3, inoculant is the cheapest type of input in the promoted packages and it clearly increases additional grain yield and additional revenue. One would therefore expect usage of inoculant to be highest. Sadly, due to the unavailability of the input on the local markets, this has not been the case in reality.

Table 5.5 *Cost-Benefit Analysis: Adaptation settings for soybean (in US$/ha^{-1})*

Usage orientation	Investment required	Production orientation 1			Production orientation 2		
		Add. revenue	Costs marketing	Total Net Present Profit	Add. revenue	Costs marketing	Total Net Present Profit
Soybean							
No fertilizer, no inoculant; saved seed	87.92	84.42	12.09	-4.31	54.43	9.59	-11.9
No fertilizer, no inoculant; bought seed	96.11	84.42	12.09	-6.57	54.43	9.59	-14.16
No fertilizer; inoculant, saved seed	96.88	149.70	17.16	9.85	96.52	17.02	-4.80
No fertilizer; inoculant, bought seed	105.07	149.70	17.16	7.59	96.52	17.02	-7.07

Production orientation 1 = 50 percent of crop sold to trader, 25 percent sold on local market, 25 percent kept for own consumption; Production orientation 2 = 25 percent of crop sold to trader, 25 percent sold on local market, 50 percent kept for own consumption. Output prices (US$/kg): soybean farm-gate/producer = 0.32 market/consumer = 1.20.

5.3 Concluding remarks

In this chapter I assessed the costs and benefits that are associated with the usage of a set of relevant agricultural technologies in northern Ghana. Considering the presented profitability estimations, low usage rates are expected. If farmers are not able to earn a profit from taking up the technologies, they cannot generate enough cash for next season's investments unless they use some other source of income. Even if they possess other sources of income, they will likely not invest surplus money into technologies for legumes; in most cases, there is no (significant) profit to be generated. In addition, even if there is a predicted profit margin, farmers may possess a high rate of time preference. This implies that farmers prefer cash sooner rather than later. As an alternative to fully taking up the promoted sets of technologies, farmers adapted the input packages to their personal circumstances. Since farmers continue to grow legume crops and usage patterns for low-cost inputs are relatively high, one would expect that current types of adaptation, leaving out high-cost inputs, is financially more beneficial for farmers in most cases. I show that most profitability estimates are slightly better when not taking up fertilizer but taking up inoculant. For example, when comparing the setting in which a farmer does not use fertilizer, but uses inoculant and newly bought seed, the total net present profit (7.59 US$/ha-1 in production orientation 1 and -7.07 US$/ha-1 in production orientation 2) is higher than the setting where the farmer uses subsidized fertilizer, inoculant and newly bought seed (-2.14 US$/ha-1 in production orientation 1 and -26.75 US$/ha-1 in production orientation 2). Thus, when a farmer applies inoculant and no fertilizer predicted profit is better. Nevertheless, usage of inoculant was low, most likely due to its unavailability on the market.

Important to understand is that, having made several assumptions, I limit the validity and potential generalization of my results. I therefor clearly state that the cost-benefit situations only serve as an illustration; they allow me to analyse whether or not the no money reasoning, discussed in Chapter 4, is plausible. Withstanding the results, I do not argue that usage is always, or may never be, profitable. In reality, profitability of input usage will be highly dependent on the underlying agro-ecological, socio-economic and institutional circumstances of the household (Chirwa, 2005). Variation in costs, benefits, and prices determine which scenario is most relevant for a farmer. In addition, it can be argued that I left out several observable costs, such as interest on loans. Many farmers bought mineral fertilizer with a loan arranged by the MoFA. Since I have no further information on the interest rate of this loan and because the loan was only available in the Upper East region, the settings I sketched do not consider the loan. Last, I calculated the costs for weeding *once*. The N2Africa project recommended three times weeding, which would mean that the associated opportunity costs are higher if a farmer conforms to this recommendation.

6 Factors Related to Usage Behaviour

In the previous chapter I argue that, due to the unprofitability of certain combinations of technologies, farmers may face a cash constraint at the beginning of the next season or do not wish to invest their limited resources in inputs for legume crops. This finding substantiates the "no money" reason given by farmers for not using mineral fertilizer on their legume crops in 2017. However, it is expected that farmers' willingness to invest also correlates with numerous other factors besides the profitability of taking up the technologies. In this chapter I aim to answer my fourth research question. While taking into account several socioeconomic household- and farm characteristics, I explore how financial constraints and farmers' risk preference were associated with technology usage in 2017.

The following analysis is *not* of a causal nature. If one is only interested in this, skip this chapter. The data frame and project design did not lend itself to make inferences about causality. Furthermore, because of the limited amount of data, I could not include all relevant variables. The analysis is therefor subject to omitted variable bias. This reduces the internal validity of my estimations. I also include a great number of estimations, because I addressed each technology. Multiple hypothesis testing brings with it problems. For example, any results in one of the many estimations may only be so due to chance. Nevertheless, I included the results in this chapter to help identify weak links in the farmer-to-market chain, provide information for future project assessments, and provide topics for new hypotheses that can be tested in the future. In what follows, I present the underlying econometric model: a generalized linear mixed probit model. Second, I present and discuss the results of several estimations. I conclude this chapter with some remarks.

6.1 Probit model

6.1.1 Econometric strategy

My goal is to estimate how the probability of taking up agricultural technologies was correlated with (1) having food shortage in May, (2) transaction costs, (3) risk preference, and (4) usage of a MoFA mediated loan for mineral fertilizer. I have constructed a generalized linear mixed probit model to estimate how the hypothesized independent variables correlate with variation in usage behaviour of several relevant technologies. I use the following econometric specification

$$p_i = Pr(Y_i = 1) = \beta_{cons} + X_i \beta_1 + \alpha_i + \varepsilon_i \quad (2)$$

Where Y_i represents the probability household *i* deciding to take up a given input. β_{cons} is the constant. X_i is a vector of variables of interest which are hypothesized to correlate with technology usage. B_1 are the coefficients associated with this vector. α_i represent district-specific random effects. ε_i is a household specific error term. In this formulation, Y_i is a dichotomous dependent variable taking value one when the farmer uses a specified technology in 2017. I specify Y_i in more detail in the next paragraph.

I assess technologies that are widely taken up in 2017. These are the dichotomous dependent variables (Y_i)

A. mineral fertilizer for soybean (1),

B. purchased seed for (2) soybean and (3) groundnut, and

C. saved seed for (4) soybean and (5) groundnut.

Since I am interested in the effect of economic determinants on usage behaviour, the variables I test are all, in some way or another, associated with either heterogeneous costs of usage or supply-side constraints. I clarify this in the following paragraphs.

a. Food shortage in May. First, I consider a food shortage variable. I assume that households who experienced food shortage in May are subject to a cash constraint. Assuming that households do not reduce their food consumption when facing a production deficit – i.e. a constant consumption pattern, these households have to set aside cash to purchase food to feed their members. As a result, this cash is not available to purchase agricultural technologies. This variable may therefor also serve as an indication of farmers' time preference. I assume that the food shortage in May variable is exogenous; it depends on technology usage in 2016, but not on usage in 2017.

b. Distance to town. Second, I consider the effect of transaction costs on usage behaviour. High transaction costs are indications of market failures and form a barrier that restrict farmers from accessing, in this case, input markets (Alene et al., 2008). I therefor expect transaction costs to have a negative effect on usage behaviour. In Chapter 2, I discuss how transportation costs are considered reasonable first approximations of transaction costs in a smallholder farmer setting (Binswanger & Rosenzweig, 1986 as cited in Omamo, 1998; Omamo, 1995 as cited in Omamo 1998). I use a GIS-derived distance variable as the exogenous variable that proxies for transaction costs. In this particular estimation, a bigger distance to the nearest market town was expected to negatively correlate with usage.

c. Risk preference. Third, I analyse the effect of farmers' risk preference on usage. Risk preference reflects farmers' subjective way of dealing with certain risk-bearing factors (Feder & Umali, 1993; Simtowe, 2006). In this case, I expect risk preference to be positively correlated to usage – the higher the score, the higher the willingness to take risk. It can be argued that the variable is exogenous, because the questions from which it is derived are uncorrelated with factors that correlate with usage decisions. However, this may not hold always. For example, a farmer with a high risk preference may have obtained more income through other ventures, which increases wealth. Wealth, in turn, correlates with usage. I try to control for this by adding wealth control variables in the third model.

d. MoFA mediated loan in the Upper East region. Fourth, I consider the impact of a MoFA-mediated loan on mineral fertilizer usage. This loan can be considered as an indicator for access to financial capital. The availability of credit, in turn, is positively associated with usage of agricultural technologies (Feder & Umali, 1993). In several districts in northern Ghana the MoFA provides smallholder farmers with the voluntary opportunity to get a loan to purchase subsidized fertilizer. The loan is, theoretically, available to all smallholder farmers and is therefore uncorrelated to any particular characteristic. As such, I assume the variable is exogenous. Observations from the field suggest that access to the loan decreased the bigger the distance from a community to the district capital (field note, November, 2018). I therefor control for the distance to the nearest town. I expect usage of the MoFA loan to positively correlate with usage behaviour. Since the MoFA loan was not available in Yendi and Savelugu - Northern region, I exclude the observations in these districts from the analysis. Roughly, this halves the sample size. In order to keep some explanatory power, I omit several control variables from the estimated models. If possible, I kept variables that are numeric – e.g. household size and land size. I also keep the extension variable and in the last estimation the distance to town variable.

The analysis. The analysis consists of two parts. First, I assess the effect of each separate independent variable on all dependent variables (the relevant technologies). In these models, I gradually control for household- and farm-level characteristics. To clarify this, I have visualised this econometric strategy in figure 6.1. First, I control for household size, age of the household head, gender of the farmer, and education. These are recognized determinants in the adoption literature, discussed in Chapter 2. In addition, I add an extension variable to control for the number of visits received by any agricultural extension service during the rainfall season of 2017. The extension variable is used to proxy for farmers' access to agricultural information. Second, I control for two farm-level characteristics: farm size and value of livestock owned in TLU (HarvestChoice, 2011). Both variables can serve as proxies for household wealth as well as for capacity to bear risk (Wossen et al., 2015). For the MoFA loan variable, I add a distance to town variable to consider the expected relation between distance and access to the loan.

Second, I assess the effect of the four main variables of interest together. Per dependent variable, I estimate three models. In the first model, I do not include the MoFA loan variable – this variable is only relevant for the Upper East region – or any controls. For the second estimation, I add a selection of household- and farm-level controls. I have chosen these controls because (1) they are relevant in the adoption literature and (2) because they are (if possible) numeric instead of categories. In the final model, I add the MoFA loan variable, but this model is without any controls because of the limited amount of observations. All models include district-level random effects to control for unobserved effects that do not vary between observations in the same district.

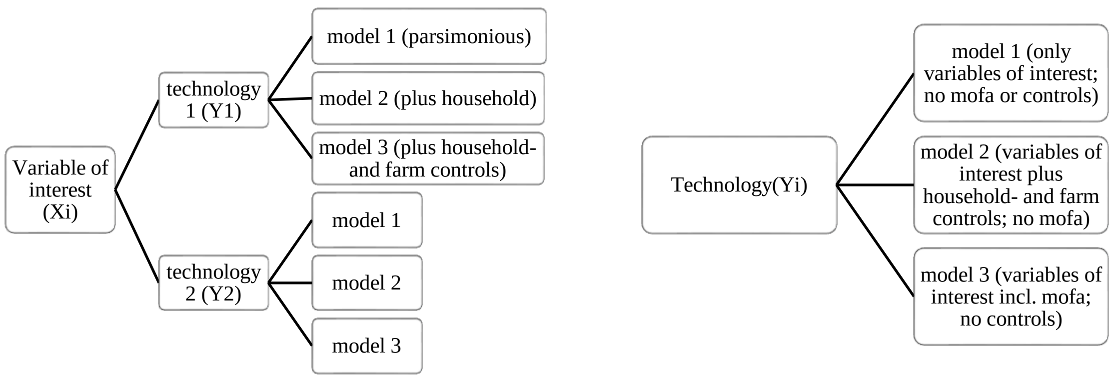

Figure 6.1 *Visualisation of econometric strategies. Left: assessment of separate independent variable. Right: assessment of models including all independent variables.*

6.1.2 Probit regression results

I present the econometric results for each of the four variables of interest in the separate tables 6.2 (food shortage in May), 6.3 (distance to town), 6.4 (risk preference), and 6.5 (the MoFA loan). In each table I analyse the effect of the variable of interest on the usage of three technologies; and for each technology I estimate three models. The analysed technologies are (1) mineral fertilizer for soybean, (2) bought seed for soybean and (3) groundnut, and (4) saved seed for soybean and (5) groundnut. Due to a lack of variation in usage, there is no use in estimating models for mineral fertilizer for groundnut or for weeding, row planting and inoculant. In table 6.5, I present several additional estimations with which I analyse the combined effect of the hypothesized determinants on the usage of the dependent variables. Diagnostic statistics are given at the bottom of the tables. The pseudo R^2 compares the log-likelihood, log L, with the log likelihood that would have been obtained with only the constant

(Dougherty, 2011). Although this value does not have a natural interpretation, it serves as a test for the goodness-of-fit of the models. Generally, values between 0.2 and 0.4 indicate that the model has a good fit (Lee, 2013). Corresponding pseudo R^2's are generally below 0.2, suggesting that there are important variables missing from the model. This is not entirely unexpected – it is hard to predict human behaviour, since it is associated with numerous (unobservable) factors (Dougherty, 2011).

a. Food shortage in May. I present the results for the effect of having food shortage in May on usage in table 6.2. The variable serves to measure the level of cash constraints a household experienced in 2017. Contrary to expectations, whether a household experienced food shortage at the beginning of the rainfall season did not influence the probability to take up mineral fertilizer for soybean or bought seed for soybean or groundnut within the targeted population. There can be multiple explanations for these results. For example, the severity and duration of the period with food shortage was not considerable enough to influence production decision. Otherwise, household access to social safety nets in the community may have prevented food shortage in May to have a significant impact. Regrettably, my dataset does not allow me to infer on this.

There is one weak, positive significant result for saved soybean seed, but this effect is lost when controlling for farm-level characteristics (estimation 11). The result does make sense. As is shown in Chapter 5, saving soybean seed is cheaper than purchasing it on the market. When households face cash constraints, such as having food shortage in May, it is a logical decision to use saved seed instead of buying new seed. Gender seems to be correlated with usage behaviour of saved seed as well (estimations 11, 12, and 68). In both table 6.2 and table 6.6, whether a farmer was male is positively correlated with the probability to take up saved soybean seed.

b. Distance to town. As discussed, transaction costs are proxied for by the distance to the nearest market town. I present the results of the models in table 6.3. I only report weakly statistically significant effects of the distance to the nearest market variable for bought seed for soybean (estimations 19, 20, and 21). This finding is contrary to expectations. The estimates imply that the larger the distance to town, the more likely it is for a farmer to have purchased seed for soybean on the market. This finding is confirmed in table 6.6, with similar results for bought soybean seed (estimations 61 and 62). One would expect the opposite. It has regularly been observed and reported in the literature that transportation increased transaction costs, which reduces incentives to purchase agricultural inputs on the local market (Omamo, 1998). Interestingly, also education is weakly and positively significant (estimations 20 and 21). One explanation for the contradictory results is that farmers who have had a higher education know the benefits of applying good improved seed and are aware that, because they live on a greater distance from town, they have to intensify more to increase their profit and pay for the costs of distance. The costs for them to market their grain, but also for other commodities in their lives, is higher. Therefore they have a bigger need to intensify production, which means buying and applying good inputs from the market. Results for the other technologies are rather uninformative.

c. Risk preference. I present the results for the risk preference variable of interest in table 6.4. Risk preference is positively and statistically significantly associated with usage of mineral fertilizer for soybean (estimations 31, 32, and 33). A higher risk preference score increased the probability of taking up mineral fertilizer for soybean within the targeted population. This is in line with expectations. Interestingly, land size is also positively and weakly statistically significant (estimation 33). The complementarity between the risk variable and the land size variable is what one would expect: land size is a recognized proxy for capacity to bear risk. Households with more land can afford to be more risk-taking than farmers with less land. These results are confirmed in estimations 58 and 59 in table 6.6. Risk preference is statistically insignificant for all seed-related estimations. In addition, risk preference is negatively and statistically significantly related to usage of saved soybean seed (estimations 41 and 42). Gender also influenced this probability. Male risk taking farmers were less likely to use saved seed and more likely to buy it new, which makes sense if one considers that buying seed requires a larger investment. Risk taking farmers are more willing to make such investments. One caveat with the risk preference variable is that it is highly subjective and the scores may be subject to measurement bias.

d. MoFA mediated loan in the Upper East region. I present the results for the MoFA mediated loan in table 6.5. Also contrary to expectations, the results for the MoFA loan are statistically insignificantly associated with usage of mineral fertilizer and seed. This finding is not in line with the academic theory that argues that access to credit enhances usage (Feder & Umali, 1993; Dzadze et al., 2012). The loan provided farmers with the opportunity to purchase fertilizer without having to save cash beforehand. It can therefor alleviate the cash constraint. Considering the results, however, the mediated loans do not seem to have influenced usage behaviour for the specified agricultural technologies. One reason for the missing effect is that the loan was not mediated evenly between all districts. I noticed that households living closer to the main centre (Bawku town) had better access to the mediated loans (field note, November, 2017). Nevertheless, controlling for distance to town or district random effects does not seem to influence the results.

6.2 Concluding remarks

The findings in this chapter suggest that farmers' risk preference was positively correlated to usage of mineral fertilizer and saved seed for soybean in 2017. Only in some cases there appears to be a weak and contradictory correlation between usage and distance to the nearest town. The MoFA mediated loan in the Upper East region and whether a household experienced food shortage in May do not seem to be associated with usage behaviour in 2017. The results can substantiate my finding in Chapter 5 that usage is not always profitable. First, if profits – and resulting cash flows - are uncertain, risk-averse farmers will likely not take up a technology. In turn, risk-taking farmers are more likely to take up technologies if potential profits are uncertain. I discuss the relationship between the findings in my separate chapters in more detail in Chapter 7.

As I discussed in the beginning of this chapter, there are some limitations to the internal and external validity of my econometric analyses. First, there is no counterfactual and differences over time may be due to innumerable (hidden) factors and temporal effects. The available data frame did not allow me to include some of the gathered variables and others are unobserved. This is reflected in the low pseudo R2's and the sometimes strong influence of the constant in the estimated models. In the following chapter I will discuss what kind of unobservables may have been important. In addition, I test multiple hypotheses with various estimations. This brings with it issues of multiple hypothesis testing, where any of the results may only be due to chance. Second, the sampled population consists of farmers whom have participated voluntarily. This has limited the external validity of my results, because the estimations can only address within-group variation. Any results may only be generalizable to farmers who have participated in similar trials in the N2Africa programme.

Table 6.1 *Dependent- and independent variable list*

Dependent variables	
Mineral fertilizer soybean	Utilization of any kind of mineral fertilizer on soybean 1 = true; 0 = otherwise
Bought seed soybean	Utilization of any kind of improved soybean seed, purchased from a (market) trader 1 = true; 0 = otherwise
Bought seed groundnut	Utilization of any kind of improved groundnut seed, purchased from a (market) trader 1 = true; 0 = otherwise
Saved seed soybean	Utilization of any kind of improved soybean seed, saved from last season's harvest 1 = true; 0 = otherwise
Saved seed groundnut	Utilization of any kind of improved groundnut seed, saved from last season's harvest 1 = true; 0 = otherwise

Independent variables	
Food shortage May	Household experienced food shortage in May 2017 1 = true; 0 = otherwise
MoFA loan	Household made use of a MoFA mediated loan to purchase subsidized mineral fertilizer 1 = true; 0 = otherwise
Distance to town	in kilometres
Risk preference	Score of two scaled question between 0 and 14 0 = completely risk-averse; 14 = completely risk-taking
Household size	number of members living in the household
Age head category	1 = 18-25, 2 = 25-50, 3 = 50-60, 4 = >60
Gender farmer	1 = male; 0 = female
Education hhh	Minimum of secondary education of household head. 1 = true; 0 = otherwise
Extension visits	1 = 1, 2 = 2, 3 = 3, 4 = >3
Land size	in hectares
TLU	value of livestock owned in Tropical Livestock Units

Table 6.2 *Influence of having food shortage in May on usage of agricultural technologies in 2017*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dependent variable:	*Y1 = mineral fertilizer soybean*			*Y2 = bought seed soybean*			*Y3 = bought seed groundnut*			*Y4 = saved seed soybean*			*Y5 = saved seed groundnut*		
Food shortage May	-0.439	-0.937	-0.942	-0.0425	-0.0440	-0.0691	-0.689	-0.173	-0.123	0.251	1.329*	1.282	NA	-0.357	-0.374
	(-0.98)	(-1.55)	(-1.43)	(-0.11)	(-0.07)	(-0.12)	(-1.38)	(-0.28)	(-0.18)	(0.64)	(2.06)	(1.95)		(-0.70)	(-0.71)
Household size		0.00150	0.0227		-0.0401	-0.0393		0.00890	0.0133		-0.0350	-0.0313		0.0110	0.0110
		(0.05)	(0.51)		(-1.19)	(-1.14)		(0.33)	(0.44)		(-1.19)	(-1.04)		(0.46)	(0.46)
Age head category		-0.0168	-0.0299		0.156	0.150		-0.0161	0.0405		0.229	0.230		0.249	0.246
		(-0.06)	(-0.09)		(0.57)	(0.54)		(-0.06)	(0.14)		(0.81)	(0.81)		(1.10)	(1.09)
Gender farmer		-0.482	-0.519		-0.646	-0.582		0.404	0.325		1.859**	1.973**		0.110	0.111
		(-0.80)	(-0.78)		(-1.16)	(-1.00)		(0.61)	(0.46)		(2.80)	(2.78)		(0.21)	(0.21)
Education hhh		0.826	0.734		0.762	0.790		1.112	1.034		-0.654	-0.709		-1.476*	-1.476*
		(1.00)	(0.81)		(1.33)	(1.32)		(1.80)	(1.53)		(-0.99)	(-1.05)		(-2.02)	(-1.99)
Extension visits		-1.375*	-1.759*		0.232	0.248		-0.131	-0.216		0.202	0.211		0.427	0.429
		(-2.26)	(-2.24)		(0.42)	(0.45)		(-0.42)	(-0.62)		(0.49)	(0.51)		(1.68)	(1.66)
Land size			0.120			-0.0341			0.101			-0.0155			-0.00783
			(1.58)			(-0.45)			(1.79)			(-0.22)			(-0.14)
TLU			-0.124			0.00920			-0.0604			-0.0314			0.000149
			(-1.35)			(0.15)			(-1.13)			(-0.61)			(0.00)
Constant	-0.141	5.273*	6.392*	-0.799**	-1.565	-1.537	-0.576	-0.933	-1.100	-0.141	-2.408	-2.361	NA	-2.093	-2.051
	(-0.32)	(2.33)	(2.22)	(-3.26)	(-0.72)	(-0.70)	(-1.58)	(-0.60)	(-0.65)	(-0.47)	(-1.38)	(-1.32)		(-1.62)	(-1.52)
District-level effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes
_cons	0.559	1.306	2.174	4.00e-34	4.01e-34	2.65e-34	0.0415	3.48e-32	2.15e-42	0.122	0.316	0.353		9.87e-43	5.43e-34
	(1.14)	(1.09)	(1.06)	(0.00)	(0.00)	(0.00)	(0.21)	(0.00)	(0.00)	(0.67)	(0.81)	(0.81)	NA	(0.00)	(0.00)
N	53	51	51	53	51	51	55	50	50	53	51	51	NA	50	50
pseudo R^2	.009	.061	.111	.12	.126	.128	.047	.072	.088	0.043	0.036	0.047		0.132	0.133

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6.3 *Influence of distance to nearest town on usage of agricultural technologies in 2017*

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Dependent variable:	*Y1 = mineral fertilizer soybean*			*Y2 = bought seed soybean*			*Y3 = bought seed groundnut*			*Y4 = saved seed soybean*			*Y5 = saved seed groundnut*		
Distance to town	-0.0187	0.0207	0.0294	0.108*	0.142*	0.148*	-0.00232	-0.0212	-0.0490	-0.0708	-0.0920	-0.0930	0.00850	0.0484	0.0544
	(-0.37)	(0.34)	(0.44)	(2.13)	(2.14)	(2.18)	(-0.05)	(-0.40)	(-0.81)	(-1.53)	(-1.59)	(-1.59)	(0.25)	(1.12)	(1.19)
Household size		-0.0156	0.000600		-0.0469	-0.0487		0.00108	0.00491		-0.0226	-0.0189		0.0119	0.0105
		(-0.51)	(0.01)		(-1.29)	(-1.23)		(0.04)	(0.16)		(-0.83)	(-0.66)		(0.49)	(0.43)
Age head category		0.0258	-0.00689		0.271	0.268		-0.00576	0.0517		0.165	0.184		0.250	0.245
		(0.09)	(-0.02)		(0.89)	(0.86)		(-0.02)	(0.18)		(0.61)	(0.66)		(1.11)	(1.09)
Gender farmer		0.0364	-0.0333		-0.238	-0.000302		0.596	0.434		1.020*	1.302*		0.493	0.521
		(0.07)	(-0.06)		(-0.46)	(-0.00)		(1.09)	(0.76)		(2.08)	(2.25)		(1.16)	(1.19)
Education hhh		1.113	1.036		1.445*	1.561*		1.467*	1.288		-1.000	-0.969		-1.270	-1.205
		(1.33)	(1.12)		(2.05)	(2.06)		(2.19)	(1.78)		(-1.44)	(-1.35)		(-1.67)	(-1.55)
Extension visits		-1.350*	-1.769*		-0.142	-0.103		-0.172	-0.256		0.445	0.468		0.435	0.459
		(-2.22)	(-2.25)		(-0.21)	(-0.15)		(-0.54)	(-0.73)		(1.01)	(1.05)		(1.68)	(1.75)
Land size			0.126			-0.0799			0.102			-0.0513			-0.0153
			(1.68)			(-0.83)			(1.71)			(-0.73)			(-0.27)
TLU			-0.118			0.0179			-0.0656			-0.0426			0.0190
			(-1.35)			(0.23)			(-1.21)			(-0.76)			(0.45)
Constant	-0.139	4.420*	5.657*	-1.905***	-2.208	-2.270	-0.851	-0.702	-0.530	0.644	-1.339	-1.349	-0.00798	-2.950*	-3.087*
	(-0.23)	(2.06)	(2.05)	(-3.31)	(-0.82)	(-0.81)	(-1.61)	(-0.44)	(-0.30)	(1.32)	(-0.79)	(-0.77)	(-0.02)	(-2.19)	(-2.20)
District-level effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	0.540	1.342	2.208	3.53e-35	1.30e-33	1.68e-33	0.216	2.73e-32	7.28e-35	0.131	0.444	0.561	7.81e-34	7.18e-34	1.61e-33
	(1.10)	(1.10)	(1.08)	(0.00)	(0.00)	(0.00)	(0.59)	(0.00)	(0.00)	(0.73)	(0.93)	(0.96)	(0.00)	(0.00)	(0.00)
N	52	50	50	52	50	50	53	49	49	52	50	50	53	49	49
pseudo R^2	.01	.066	.116	.129	.119	.131	.027	.083	.104	0.046	0.043	0.056	0.098	0.125	0.125

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6.4 *Influence of farmers' risk preference on usage of agricultural technologies in 2017*

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Dependent variable:	*Y1 = mineral fertilizer soybean*			*Y2 = bought seed soybean*			*Y3 = bought seed groundnut*			*Y4 = saved seed soybean*			*Y5 = saved seed groundnut*		
Risk preference	0.232^{**}	0.304^{**}	0.441^{*}	0.0629	0.0598	0.0564	0.0281	-0.0862	-0.0267	-0.0960	-0.155^{*}	-0.165^{*}	0.0281	0.0925	0.102
	(2.84)	(2.64)	(2.56)	(1.00)	(0.80)	(0.74)	(0.46)	(-0.99)	(-0.28)	(-1.70)	(-1.99)	(-2.06)	(0.54)	(1.29)	(1.31)
Household size		0.00335	0.0188		-0.0376	-0.0374		0.000904	0.0111		-0.0237	-0.0197		0.0153	0.0174
		(0.10)	(0.41)		(-1.14)	(-1.11)		(0.03)	(0.36)		(-0.91)	(-0.72)		(0.59)	(0.66)
Age head category		-0.0236	-0.0558		0.132	0.130		0.0745	0.0730		0.170	0.174		0.174	0.168
		(-0.08)	(-0.16)		(0.48)	(0.46)		(0.27)	(0.25)		(0.67)	(0.66)		(0.74)	(0.71)
Gender farmer		-0.853	-1.590		-0.723	-0.670		0.684	0.408		1.447^{**}	1.727^{**}		0.231	0.182
		(-1.35)	(-1.61)		(-1.48)	(-1.24)		(1.19)	(0.66)		(2.92)	(2.86)		(0.52)	(0.38)
Education hhh		-0.130	-0.993		0.618	0.657		1.632^{*}	1.210		-0.324	-0.394		-1.838^{*}	-1.919^{*}
		(-0.14)	(-0.87)		(1.03)	(1.04)		(2.03)	(1.42)		(-0.50)	(-0.58)		(-2.27)	(-2.27)
Extension visits		-0.991	-1.200		0.298	0.310		-0.203	-0.222		-0.226	-0.207		0.464	0.462
		(-1.41)	(-1.40)		(0.57)	(0.59)		(-0.62)	(-0.63)		(-0.52)	(-0.47)		(1.74)	(1.69)
Land size			0.241^{*}			-0.0250			0.0981			-0.0389			0.0197
			(2.25)			(-0.32)			(1.57)			(-0.52)			(0.33)
TLU			-0.0938			0.00904			-0.0507			-0.0448			-0.00729
			(-0.93)			(0.14)			(-0.96)			(-0.91)			(-0.17)
Constant	-2.386^{**}	1.113	0.390	-1.344^{*}	-2.228	-2.204	-1.091	-0.490	-1.073	0.785	1.297	1.399	-0.167	-2.950^{*}	-3.052^{*}
	(-2.78)	(0.42)	(0.12)	(-2.34)	(-1.07)	(-1.04)	(-1.80)	(-0.30)	(-0.59)	(1.49)	(0.65)	(0.68)	(-0.38)	(-2.18)	(-2.10)
District-level effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	0.515	1.106	1.791	2.96e-34	6.92e-34	1.41e-33	0.182	1.48e-32	1.75e-35	0.0371	0.0680	0.136	4.95e-35	9.33e-35	3.12e-36
	(1.00)	(0.91)	(0.89)	(0.00)	(0.00)	(0.00)	(0.57)	(0.00)	(0.00)	(0.27)	(0.29)	(0.44)	(0.00)	(0.00)	(0.00)
N	53	51	51	53	51	51	54	49	49	53	51	51	54	49	49
pseudo R^2	.009	0.061	0.081	.0.122	0.138	0.137	.0311	0.083	0.089	0.057	0.060	0.061	0.095	0.132	0.133

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6.5 *Influence of MoFA loan in the Upper East on usage of agricultural technologies in 2017*

	46	47	48	49	50	51	52	53	54	55	56	57
Dependent variable:	*Y1 = mineral fertilizer soybean*			*Y2 = bought seed soybean*			*Y4 = saved seed soybean*			*Y5 = saved seed groundnut*		
MoFA loan	5.924	6.908	8.715	0.187	0.125	0.196	-0.908	-0.833	-0.772	5.991	6.232	NA
	(0.02)	(0.01)	(0.01)	(0.34)	(0.21)	(0.26)	(-1.64)	(-1.35)	(-1.15)	(0.02)	(0.02)	
Household size		-0.0332	-0.0321		-0.0296	0.00567		-0.0457	-0.0460		0.0336	NA
		(-0.59)	(-0.54)		(-0.74)	(0.12)		(-1.12)	(-0.98)		(0.65)	
Extension visits		-0.759	-0.594		0.269	0.188		-0.178	-0.00785		-0.248	NA
		(-1.43)	(-0.97)		(0.47)	(0.27)		(-0.37)	(-0.01)		(-0.74)	
Land size			-0.340			-0.459			-0.0519			NA
			(-0.91)			(-1.12)			(-0.28)			
Distance to town			-0.0499			0.0975			-0.112			NA
			(-0.55)			(1.55)			(-1.85)			
Constant	-0.565	2.466	3.147	-0.792*	-1.402	-1.446	-0.000000326	1.191	1.627	-0.566	-0.261	NA
	(-1.59)	(1.23)	(1.36)	(-2.11)	(-0.65)	(-0.53)	(-0.00)	(0.65)	(0.78)	(-1.59)	(-0.18)	
District-level effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
_cons	8.38e-16	1.11e-36	7.63e-33	3.43e-34	6.55e-34	9.16e-37	2.93e-33	1.08e-37	2.94e-34	1.29e-35	1.02e-33	NA
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
N	25	25	25	25	25	25	25	25	25	22	22	
pseudo R^2	.1767	.1357	.1512	.1275	.1307	.1285	0.111	0.127	0.153	0.083	0.084	

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Due to a lack of explanatory power, the estimations for purchased groundnut seed and estimation 57 for saved groundnut seed are omitted.

Table 6.6 *Influence of selected variables of interest on usage of agricultural technologies in 2017*

	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Dependent variable:	*Y1 = mineral fertilizer soybean*			*Y2 = bought seed soybean*			*Y3 = bought seed groundnut*			*Y4 = saved seed soybean*			*Y5 = saved seed groundnut*		
Food shortage May	0.265	-0.135	0.822	0.536	0.927	0.185	-0.818	-0.574	NA	-0.342	0.677	0.372	-0.106	0.0917	-1.916
	(0.50)	(-0.17)	(0.76)	(1.08)	(1.24)	(0.21)	(-1.77)	(-0.76)		(-0.76)	(0.98)	(0.48)	(-0.28)	(0.16)	(-1.05)
Risk preference	0.262**	0.448**	0.657	0.143	0.0998	-0.0198	0.00279	-0.0350	NA	-0.129	-0.125	0.174	0.0343	0.0982	0.116
	(2.84)	(2.81)	(1.32)	(1.77)	(1.13)	(-0.13)	(0.04)	(-0.38)		(-1.93)	(-1.64)	(1.23)	(0.59)	(1.32)	(0.57)
Distance to town	0.0238	-0.0226	0.0789	0.145*	0.177*	0.120	-0.00246	-0.0603	NA	-0.0931	-0.0495	-0.0824	0.0210	0.0743	0.215
	(0.41)	(-0.28)	(0.82)	(2.56)	(2.53)	(1.71)	(-0.06)	(-0.96)		(-1.93)	(-0.91)	(-1.36)	(0.58)	(1.52)	(1.34)
MoFA loan			6.589			-0.0213			NA			-1.016			8.834
			(0.01)			(-0.03)						(-1.39)			(0.01)
Gender farmer		-1.838			0.482			0.0650	NA		1.794*			0.649	
		(-1.73)			(0.69)			(0.08)			(2.57)			(1.04)	
Household size		0.0167			-0.0491			0.0168	NA		-0.0178			0.00698	
		(0.38)			(-1.28)			(0.67)			(-0.68)			(0.32)	
Education hhh		-1.321			1.042			1.102	NA		-0.265			-1.473	
		(-1.41)			(1.54)			(1.35)			(-0.41)			(-1.80)	
Land size		0.220*			-0.0299			0.0914	NA		-0.0328			-0.00754	
		(2.13)			(-0.34)			(1.38)			(-0.48)			(-0.12)	
TLU		-0.0525			-0.0246			-0.0755	NA		-0.0242			-0.00202	
		(-0.75)			(-0.29)			(-1.24)			(-0.51)			(-0.05)	
Constant	-2.948*	-3.819	-7.915	-3.697**	-3.470*	-1.860	-0.430	-0.530		2.088*	0.741	-0.987	-0.367	-1.639	-2.171
	(-2.30)	(-1.94)	(-1.45)	(-3.10)	(-2.23)	(-0.91)	(-0.58)	(-0.37)		(2.22)	(0.57)	(-0.57)	(-0.54)	(-1.35)	(-1.03)
District-level effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
_cons	0.404	0.788	9.85e-33	1.19e-34	7.13e-39	3.25e-33	6.26e-31	3.08e-49	NA	0.0272	0.0749	5.41e-36	2.74e-34	3.52e-33	4.86e-33
	(0.90)	(0.89)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.22)	(0.33)	(0.00)	(0.00)	(0.00)	(0.00)
N	52	51	25	52	51	25	52	49		52	51	25	52	49	21
pseudo R^2	0.017	0.070	0.186	0.134	0133	0125	0.056	0.117		0.070	0.061	0.149	0.093	0.107	0.104

t statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Due to a lack of explanatory power, the estimations for purchased groundnut seed in estimation 66 are omitted.

7 Discussion and Conclusion

Recent studies, conducted as part of the N2Africa programme, show how tailor-made agricultural technologies for grain legumes are essential for the intensification of smallholder farming systems. Usage of these technologies is expected to increase farmers' food production and income, and decrease pressure on the surrounding environment (World Bank, 2008; Vanlauwe et al. 2010; Vanlauwe et al. 2014; Ronner et al., 2016). To shed light on post-project usage patterns and the effect of input usage on farmers' income, I explored usage behaviour of farmers who had previously participated in the focal adaptation trials of the N2Africa programme in Ghana. N2Africa, a programme funded by the Bill and Melinda Gates Foundation, is set up to directly address smallholder food- and nutrition insecurity in SSA and to increase rural incomes through increased agricultural productivity. This programme is led and coordinated by the Wageningen University and Research Centre and the International Institute of Tropical Agriculture (IITA). Legume crops are promoted because they capture nitrogen from the air and fix it in the soil, enriching the soil and reducing the necessity to utilize external inputs such as mineral fertilizer, thereby decreasing the impact of agricultural on the natural environment.

My results confirm that there is a pattern between usage behaviour and several economic determinants, although the evidence is mixed and sometimes in contrast to (agronomic) expectations. The answers to my research questions are the following. First, not all of the adaptation trial farmers from 2015 and 2016 took up (components of) the originally distributed agricultural technology options for soybean and groundnut in 2017. Usage rates were low for mineral fertilizer, inoculant and purchased improved seed. In addition, usage patterns were dependent on farmers' socio-economic circumstances (research question two) and even when usage is an economically rational decision – as is the case with inoculant, the promoted inputs were not always available on the local market for purchase. Inoculant, for example, was unavailable in 2017 at all of the targeted traders. To answer my third research question, I categorized the promoted inputs into low- and high-cost inputs. Usage of high-cost inputs is low as compared to low-cost inputs, so there appears to be a link between the costliness of several of the inputs and their usage. I find evidence that the profitability of taking up several concrete technology packages is mostly negative, but that it is also highly context dependent. Evidence suggests that adaptation – i.e. only taking up components of the package - is often, though not always, financially more beneficial to farmers than fully taking up relevant technology packages. Adaptation allows farmers to leave out high-cost inputs, such as mineral fertilizer. Adding inoculant always increased profit in the adaptation settings. Last, to answer my forth research question I presented various econometric estimations that analyse the association between usage behaviour and a number of selected variables. The econometric analyses show how usage behaviour is, in several cases, correlated to farmers' risk preference and distance to the nearest market town. In the case of risk preference, risk aversion was negatively correlated to the probability to take up mineral fertilizer and negatively to the probability for saved seed for soybean. Distance to town was positively correlated to the probability to take up bought seed for soybean.

Some of the results, however, should be taken with caution. Regarding my methodology (Chapter 3), the data I collected may have been subject to measurement bias. I worked together with three translators. Each of them may have interpreted and translated my questions in their own way. Furthermore, some were on familiar terms with the respondents, which may have affected the respondents' answers. In addition, I originally included a willingness to pay module in the household survey, but due to misinterpretation the gathered data is not reliable. The same goes for the third risk preference question in this survey. The risk preference variable is based on a simplified risk elicitation score calculation method, which only gives an indication of farmers' subjective risk preference. The willingness to pay module and the third risk preference question are omitted from any of the analyses.

In Chapter 4, I present usage patterns of weeding and row planting. These practices were adopted many years before the N2Africa project came along and I do not argue that high usage of these practices is a result of project participation. I also do not include information on how many times a farmer weeded or what the spacing was between their rows (when planting in rows). The recommended amount of weeding by the project was three times per season and usage patterns in table 4.2 may have been different if I had included separate categories the number of times that is weeded. The input availability presented in table 4.6 is also not a good representation of input availability in the region. The sample of traders was small, picked non-randomly, not evenly distributed between the two regions.

In Chapter 5, one has to take caution with figure 5.1 when comparing weeding and row planting practices with the other inputs. The figure suggests that uptake of weeding and row planting is much higher because the costs of applying these practices are low. However, since the practices were already adopted many years before the N2Africa project came along, this is not the conclusion that should be drawn from the figure. The comparison between bought seed and saved seed is much more reliable for the point I intended to make. Second, I mention that the validity and generalizability of my results is limited because of the assumptions that I had to make to estimate costs and profitability. The cost-benefit situations serve as an illustration and I do not argue that usage is always or may never be profitable. In reality, profitability of input usage will be highly dependent on the underlying agro-ecological, socio-economic and institutional circumstances of the household (Chirwa, 2005). In addition, I calculated the costs for weeding *once*. The N2Africa project recommended three times weeding, which would mean that the associated opportunity costs are higher if a farmer conforms to this recommendation.

In Chapter 6, the internal and external validity of my estimations is limited due to the following factors. First, the available data frame did not allow me to include some variables and other variables of interest remain unobservable. This is reflected in the low pseudo R2's and the sometimes strong influence of the constant in the estimated models. So there is a potentially large amount of factors that may have explained variation but which I have been unable to include. My models were not suited to address this, but I expect that missing factors are related to market access and availability (based on field experiences). My only proxy for market access is distance to town. Factors such as the condition of roads, awareness about the relevant inputs, access to information on prices and inputs, or facilitated linkages between input suppliers and farmers may be associated with uptake behaviour. I also expected access to credit to be important, because based on experiences in the field in the Upper East region the loan on subsidized fertilizer seemed likely to correlate with uptake. My results do not confirm this, but I would suggest further research on this topic. In addition, I test multiple hypotheses with various estimations. This brings with it issues of multiple hypothesis testing, where results may only be due to chance. Last, many of the recognized usage determinants are endogenous. For example, income variables correlate with household wealth. Respondents from wealthier households may own mobile assets that decrease their transportation costs and as such increase the profitability of technology usage. If household wealth also affects usage decisions directly, then profitability and household wealth are correlated. Last, decisions to take up technologies are often made simultaneously. For example, a farmer may decide to purchase YARA blend fertilizer together with improved seed, as is recommended by the project. To analyse this, one would need to do a multivariate probit analysis, similar to the study Marenya and Barret (2007). This would, however, require a much more extensive dataset, with more observations and more variation in usage of relevant agricultural technologies.

Limitations regarding my external validity mainly concern the design of the focal adaptation trials and of my study. Because of the trial design there was no counterfactual – a group of participants that did not receive the focal adaptation trial packages. The sampled population consists of farmers whom have participated voluntarily and within this population I was unable to take a random sample due to the limited amount of secondary data that was available. It is therefore unknown whether the selected sample is representative for (1) the focal adaptation trials in Ghana and (2) legume farmers in general. Currently, my estimations only address within-group variation and any results can only be generalized with caution to farmers who have participated in similar trials in the N2Africa programme in Ghana.

Taking into consideration the limitations of my study and results, I carefully draw some implications of my study. First, it is evident that there are mismatches in supply and demand of several of the promoted agricultural inputs. Within the target population, farmers indicated their interest in some the promoted inputs, such as TSP and inoculant, and traders were often aware of this demand. Nevertheless, many of these inputs were unavailable on the local markets. This suggests that the market chain is not functioning properly. Either agro-input traders cannot get the promoted inputs or they may not think it worthwhile to purchase and sell them. Herein lies a role for local agricultural extension services: to mediate between the farmer and the agro-input trader. It is therefore important to improve physical access to agricultural inputs for both agro-input traders and farmers. Changes in infrastructure, such as better roads, are therefore essential. Multi-stakeholder partnerships, a component strived for in N2Africa's vision for success, can prove to be important instruments to tackle such issues.

Second, high costs of several of the promoted inputs seem to hamper usage by smallholders whom participated in the project. This is potentially substantiated by a (subjective) output risk: farmers are not convinced of the benefits of usage and often the predicted profits are low or negative. Considering farmers' risk- and time preferences, choosing not to use relatively expensive inputs is a logical decision. If agricultural investment opportunities provide lower returns as compared to non-agricultural investments, farmers with more investment potential will likely not invest in agricultural technologies (Davis, Guiseppe, & Zezza, 2017). To increase the attractiveness of the relevant agricultural technologies, costs must be decreased and market access has to be improved. A government subsidy on fertilizer, such as is currently accessible in most regions in Ghana (Banful, 2011), is a logical first step, but it is evidently not sufficient.

In addition, access to subsidies and associated loans seems to be highly dependent on the agricultural extension services that arrange them. I did expect the MoFA loan to play a key role in usage of mineral fertilizer in the Upper East region – my results, however, do not confirm this. Nevertheless, based on experiences from the field, I argue that loan mediation concerned with agricultural technologies can play a key role in the future, if it becomes accessible to a wider range of farmers. This loan can help farmers overcome the cash constraints they face, such as when they have to choose between food for consumption and investments in agricultural technologies. Moreover, farmers are often unable to sell their surplus crop in large quantities, which decreases their expectations of successful technology usage. Herein lies a role for output aggregators, which can, again, be steered by agricultural extension services. Such aggregators could purchase farmers' legume output on contract, reducing farmers' risk of not being able to sell their surplus crop. Important to note is that the involvement of agricultural extension also increased farmers' dependency on their services. The mediation of loans, as is done in the Upper East region for mineral fertilizer, is highly dependent on the motivation and capacity of the extension services in the area. If farmers would be able to access these loans themselves, without mediation from agricultural extension services, they would not be dependent on these services and access to credit would in my opinion increase. Farmer cooperatives can counteract the sole influence of agricultural extension services and help to improve the agency and market position of farmers in northern Ghana.

Last, there may be innumerable other qualitative and cultural reasons behind usage behaviour that I have simply been unable to include in my analysis. One such example is that projects driven by western positions on agricultural modernisation often neglect local practices and customs (Volkskrant, Hebinck, 2018). The fact that many farmers adapted their usage decisions indicates that they combine local knowledge with knowledge that is disseminated to them through projects such as N2Africa. It is important to trust in farmers' agency regarding this and be open to combinations of local *and* modern practices, or to include these into baskets of options. Another example is that there may be gender difference in legume production preferences. Women smallholders in SSA tend to favour legume options that improve food security instead of those that maximise profit (Kerr et al., 2007). I have gathered no data on this subject.

What do the latter implications mean for future research? The findings of this thesis are in line with recent, and much more extensive research devoted to the N2Africa programme. Of these, Ronner et al. (2017) find that most farmers adapt best-bet technology options to their own preferences. The authors argue in favour of the provision of baskets of technology options instead of targeted options. Future studies should analyse how such a switch affects usage behaviour and productivity. In addition, I suggest that the focus on smallholder farmers and their susceptibility to inefficient linkages in the market must be increased. This can be achieved by including farmer groups into multi-stakeholder partnerships, which allow them to voice their issues and ideas. The current situation, in which poorer farmers find themselves in a poverty gap, unable to invest in agricultural technologies, prevents these farmers from intensifying their production (Frelat et al., 2015). Market access and off-farm income opportunities are essential. The former can decrease costs and supply-side constraints (also for credit and labour markets); the latter can decrease the cash constraints that farmers face, and allow them to invest in much needed agricultural technologies.

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