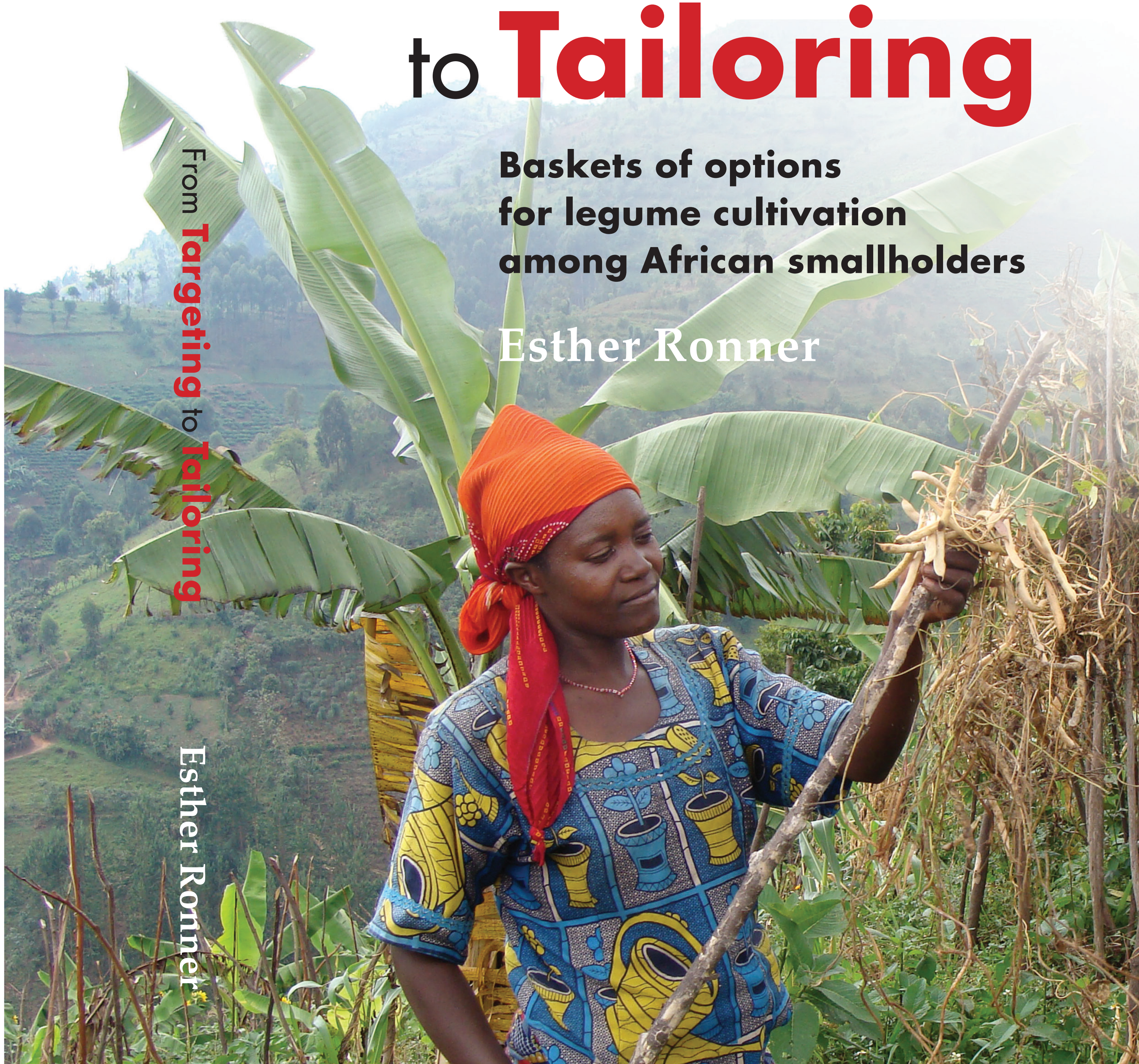
From Targeting to Tailoring

Esther Ronner



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Baskets of options for legume cultivation among African smallholders

Esther Ronner

Propositions

1. A basket of options, tailored to local conditions, is a more useful and realistic concept than ‘targeting of technologies’.
   (this thesis)
2. A change of one letter in a word, can mean a world of change.
   (this thesis)
3. Agricultural innovations will not contribute to improving the livelihoods of resource-poor farmers unless combined with institutional innovation.
4. Smallholder farming is not a viable option to achieve the necessary increases in food production to feed the world’s population.
5. Despite risks of conflict of interest, cooperation between agricultural research and the private sector is a prerequisite for agricultural development in Africa.
6. To solve societal issues, philosophy of science should be part of the curriculum of all students at a university of life sciences.
7. Interdisciplinary research advances the world, but not an individual’s PhD.

Propositions belonging to the thesis, entitled

“From targeting to tailoring: Baskets of options for legume cultivation among African smallholders”

Esther Ronner

Wageningen, 4 April 2018

From targeting to tailoring

Baskets of options for legume cultivation among African smallholders

Esther Ronner

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This research was conducted under the auspices of the C.T. de Wit Graduate School of Production Ecology and Resource Conservation

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Baskets of options for legume cultivation among African smallholders

Esther Ronner

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Wednesday 4 April 2018
at 4 p.m. in the Aula.

Esther Ronner
From targeting to tailoring: Baskets of options for legume cultivation among African smallholders
181 pages.

PhD thesis, Wageningen University, Wageningen, the Netherlands (2018)
With references, with summaries in English and Dutch

ISBN: 978-94-6343-736-3
DOI: https://doi.org/10.18174/430727

"A desk is a dangerous place from which to view the world"

John LeCarré

Abstract

The aim of this thesis was to identify niches for sustainable intensification of agriculture through legumes for different types of smallholder farmers in sub-Saharan Africa. Two legume technologies were considered: soybeans in Nigeria and climbing beans in Uganda. We applied a selection of methods from farming systems analysis, including farm typologies, on-farm try-outs, participatory methods and an *ex-ante* impact assessment.

In on-farm try-outs of soybean in Nigeria we observed a strong variability in grain yield and response to treatments. Averages of on-farm performance of technologies were of little value to estimate the benefits of a technology for individual farmers. Although we explained a reasonable percentage of the observed variability in soybean yield, the potential to use this information to predict the performance of technologies or to target technologies to a new group of farmers remained limited.

Yet, even if we understand where legume technologies work best, this does not necessarily lead to adoption of these technologies. Participatory methods applied in the co-design (i.e. technology development with farmers, researchers and other stakeholders) of improved climbing bean production practices in Uganda showed that farmers use a wider range of criteria for the evaluation of legume technologies than yield only. The co-design process resulted in a basket of options for climbing bean cultivation that included alternative options for farmers with varying production objectives, resource constraints and in different agro-ecologies. The options developed through intensive interactions with a small group of users could be used as a starting point for out-scaling to new regions through the application of an 'option-by-context' matrix developed as part of the study.

Monitoring of farmers' use and adaptation of the co-designed options on their own fields over multiple seasons revealed that the large majority of farmers did not use the combination of practices that would lead to the largest yield, but adapted the climbing bean technology. Again, we observed variability in grain yields on farmers' fields and in farmers' use of practices. Further, we found that the use of practices was inconsistent between years, which complicated the formulation of recommendations about the suitability of technologies for different types of farmers.

An *ex-ante* assessment of the farm-level effects of climbing bean cultivation demonstrated that although climbing beans improved food self-sufficiency and income, they often required increased investment and always demanded more labour than current farm configurations. Combined with a discussion with farmers, these findings improved our understanding of farm-level opportunities and constraints for the adoption of climbing beans and helped to explain

why certain choices that seem obvious at field level, may work out differently at the farm level.

Throughout this thesis work I was confronted with variability in yields and use of practices, and with inconsistencies in explanatory relationships. This complicated the identification of recommendations about the suitability of technologies for different types of farmers. A basket of options, tailored to local conditions, was judged to be more useful than narrowly specified technologies for pre-defined farm types. Only recommendation domains at the regional level were considered to have predictive value for targeting of technologies.

Although the inclusion of users' perspectives in technology development resulted in the development of relevant baskets of options tailored to local conditions, we acknowledge the trade-offs between the level of detail and the time invested in obtaining these perspectives. The incorporation of farmers' evaluations of demonstration trials in technology re-design, as well as their feedback on the testing of technologies on their own field were considered two components of this study that are relatively easy to apply in other large-scale research-for-development projects. I found only limited options to improve the benefits of legume technologies for poorer farmers. Agricultural innovations therefore need to go hand in hand with institutional innovation to truly impact the livelihoods of poor farmers.

Contents

Chapter 1

General introduction

1.1 Sustainable intensification of agriculture through legumes

Agriculture plays an important role in rural livelihoods of sub-Saharan Africa (Diao et al., 2010; Dercon and Gollin, 2014), and is crucial in achieving increases in food production in view of the expected doubling of sub-Saharan Africa's population over the next 20 years (Cleland, 2013; United Nations, 2017; World Bank, 2017). In sub-Saharan Africa, agricultural growth has largely happened through area expansion, often with natural-resource degradation (World Bank, 2007; Pretty et al., 2011; Ordway et al., 2017). Especially in areas of high population pressure, room for further expansion is limited and intensification on existing agricultural land is needed. A commonly accepted pathway for intensification of agriculture is sustainable intensification (Tilman et al., 2011; Garnett et al., 2013). Sustainable intensification has various definitions, but most agree on the principles that production of more output per unit of land, labour and capital is needed while any negative environmental impact is reduced and ecosystem services are preserved (Pretty et al., 2011; Garnett et al., 2013; Vanlauwe et al., 2014b).

One potential pathway for sustainable intensification is the integration of legumes in farming systems (Giller and Cadisch, 1995; Peoples et al., 1995). Legumes have the capacity to fix nitrogen from the air in symbiosis with *Rhizobium* bacteria and can therefore contribute to improved soil fertility and crop yields in cereal-dominated cropping systems in Africa (Droppelmann et al., 2017; Franke et al., 2017). Legumes can be grown in rotation with other crops, with the additional advantage of reducing pest and disease incidence (Sanginga, 2003; Yusuf et al., 2009); or as inter- or relay crops, often without compromising the yield of the main crop (Baldé et al., 2011; Rusinamhodzi et al., 2012). Potentially, green manure crops contribute most to soil fertility and subsequent cereal yields at plot level, but their adoption has been limited as farmers seem reluctant to invest resources in a crop that does not provide a direct return in edible grain (Franke et al., 2004; Mhango et al., 2013; Kamanga et al., 2014). Grain legumes are therefore preferred by farmers. Next to the provision of food and marketable produce, grain legumes also have important nutritional value in terms of protein, amino acids and micro-nutrients (Gibson and Ferguson, 2008). The short growing period of some legumes ensures availability of food during the hunger period in the middle of the cropping season (Franke et al., 2004; Rubyogo et al., 2010).

1.2 Improving legume productivity

Currently, legume yields among African smallholders are often far below their potential. Environmental factors limiting productivity are nutrient deficiencies (mainly phosphorus), soil acidity and moisture stress (Giller and Cadisch, 1995). The availability of indigenous rhizobium species nodulating the legume also plays a role. Although technically, legume yields in trials can be enhanced with the use of improved legume varieties, phosphate (P) based fertilizers, rhizobial inoculants or their combination (Snapp et al., 1998; Sanginga et al., 2000), on farmers' fields results are much more variable (Okogun et al., 2005; Kaizzi et al., 2012). Farmers' management decisions about plant spacing and densities, the timing of planting and weeding, pest and disease control or variability in soil fertility as a result of farmers' past management strongly influence the performance of technologies (Tittonell et al., 2008; Falconnier et al., 2016). Farm management is related to farmers' access to resources such as land, labour, capital and knowledge or information: farmers with limited access to these resources may compromise on crop management.

Legume yields therefore depend on:

$$(G_L * G_R) * E * M$$

where G_L = the legume genotype, G_R = the rhizobium strain(s) nodulating the legume, E = the biophysical environment and M = agronomic management (Giller et al., 2013). To improve legume yields, the relation between these variables needs to be understood. Given the heterogeneity of African farming systems in terms of agro-ecological and socio-economic environments (Giller et al., 2011), this requires analysis of the performance of legumes under a wide range of environments and management decisions. Understanding the environmental and management conditions under which legume technologies yield well can lead to recommendations on which farmers are likely to benefit most from the technology. When technologies are expanded to new areas, such recommendations could be used to 'target' technologies for these groups of farmers.

1.3 Tailoring legume technologies to enhance adoption

Even if we understand when and where legumes yield well, however, this does not mean that farmers will also adopt the technologies. Economic feasibility plays a role (availability of input and output markets, profitability, returns to labour), as well as socio-cultural acceptability (e.g. preference for grain legumes over green manures). Moreover, technologies need to fit within spatio-temporal niches on the farm (Giller et al., 2011; Falconnier et al., 2016; Isaacs et al., 2016). Farmers also allocate their scarce resources over different farm and off-farm activities, which means that farmers rather optimize their management of all activities than maximize investments in one crop (Collinson, 2001; Giller et al., 2006). The suitability of legumes within a farming system therefore depends on a combination of agro-ecological, socio-cultural, economic and ecological factors, together considered the 'socio-ecological niche' (Ojiem et al., 2006). Again, given the heterogeneity of African smallholder farming systems, certain technologies may fit in one situation, but not another. Moreover, technologies may need to be tailored to fit such niches (Ojiem et al., 2006; Giller et al., 2011; Descheemaeker et al., 2016b).

Tailoring of technologies requires an understanding of the multiple dimensions of the socio-ecological niche, with explicit attention for farmers' objectives, needs and constraints. To improve this understanding, participatory methods gained popularity in the 1980s, as part of farming systems research and other participatory approaches to technology development (e.g. Collinson, 2000; Almekinders and Elings, 2001; Darnhofer et al., 2012). Participatory methods were later on criticized, however, for being time-consuming, site-specific and having limited potential for out-scaling (Sumberg et al., 2003; Conroy and Sutherland, 2004). Much of the technology development therefore still focuses on solutions to problems perceived by researchers, without taking into account users' perspectives (Sumberg, 2005; Giller et al., 2009; Nelson and Coe, 2014). There is a need for approaches that accommodate these perspectives, while still producing outcomes that can be used for out-scaling to a larger group of beneficiaries.

Some definitions

Targeting: researchers recommending a particular technology to a certain region/ group of farmers/ fields within a farm.

Tailoring: fine-tuning or adapting a technology to improve the relevance of that technology for a certain region/ group of farmers (by researchers, or through co-design with farmers and other stakeholders)

Adaptation: synonymous to tailoring; or: farmers making modifications when applying a technology on their own farm.

Socio-ecological niche: the interplay of agro-ecological, socio-cultural, economic and ecological factors that determine the suitability of a technology.

Recommendation domain: defined by (Harrington and Tripp, 1984) as "a group of farmers with similar circumstances, eligible for the same recommendation"

Out-scaling can be facilitated by the use of recommendation domains (Conroy and Sutherland, 2004; Descheemaeker et al., 2016b). Recommendation domains are commonly based on agro-ecology, population density and market access (Wood et al., 1999; Nelson and Coe, 2014; Farrow et al., 2016), and are thus broader or higher-level units. Socio-economic factors such as poor access to land, labour and capital or higher-level institutional constraints are often considered *ex-post* to explain adoption (Marenya and Barrett, 2007; Mugwe et al., 2009; Kassie et al., 2015) but, building on the socio-ecological niche concept, can also form the basis for tailoring or adaptation to develop relevant technologies given certain resource constraints (Vandeplas et al., 2010; Vanlauwe et al., 2014a; Descheemaeker et al., 2016b). Farm typologies can be used to classify farmers according to their socio-economic characteristics, combined with e.g. production objectives and other sources of income (Tittonell et al., 2010; Franke et al., 2014).

1.4 Co-designing a relevant basket of options for legume cultivation

Conceptual frameworks that give practical guidance to understanding diversity and generating tailored options are farming systems analysis – evolved from farming systems research – and the Describe-Explain-Explore-Design (DEED) cycle (Giller et al., 2011; Descheemaeker et al., 2016b). Farming systems analysis consists of a range of methods that describe processes at the farm rather than the plot level, considering that decisions about the allocation of resources are largely made at this level. Methods applied in farming systems analysis include participatory research, farm typologies, experiments and modelling tools to identify opportunities for the sustainable intensification of smallholder farming systems (Giller et al., 2011). The DEED cycle is used to systematically describe the current system, explain problems and opportunities for improvement (e.g. through on-farm trials), explore the implications and trade-offs of these opportunities (e.g. through *ex-ante*, farm-level assessments), and to design relevant options for new cropping or farming systems. Central to the DEED cycle is the co-learning between researchers, farmers and other stakeholders (Descheemaeker et al., 2016b). Their involvement in all steps of the cycle aims to ensure local relevance of the developed options.

Most previous studies applied the DEED cycle once (Tittonell et al., 2009; Rufino et al., 2011; Franke et al., 2014). However, an iterative application of this cycle allows farmers to test the options, provide feedback on them and to be engaged in the re-design of options (Dogliotti et al., 2014; Falconnier et al., 2017). Moreover, following up on farmers who (dis)continue using options provides insight in the actual relevance of options for different types of farmers, as well as farmers' own adaptations to the options that could further inform the re-design of technologies. Understanding the reasons for use and adaptation of certain options is therefore considered an explicit part of the technology co-design process, not just as a measurement of adoption. Likewise, an *ex-ante*, farm level assessment of the impacts and trade-offs of different options for legume cultivation could inform the suitability of options for different types of farmers, and explain farmers' choices for certain options. This combination of approaches is expected to lead to a number of tailored, locally relevant options – together considered a 'basket of options' – applicable in particular niches.

1.5 Study objectives

The overall objective of this thesis was to identify niches for sustainable intensification of agriculture through legumes for different types of smallholder farmers in sub-Saharan Africa. I hypothesized that it would be possible to recommend specific options for legume cultivation for different types of farmers, with differences between farmers mainly relating to agro-ecological and socio-economic variables.

Specific objectives were to:

1. Understand field-level variability in legume yields and response to inputs, and evaluate the consequences of this variability for farmers' (economic) benefits and targeting of technologies *(Chapter 2)*.
2. Develop and apply a co-design process to generate a relevant basket of options for legume cultivation for different types of farmers, and develop an out-scaling tool for these options *(Chapter 3)*.
3. Understand (reasons for) use and adaptation of co-designed options for legume cultivation among different types of farmers trying out these options on their own field, and use this understanding to inform technology re-design and out-scaling *(Chapter 4)*.
4. Explore farm-level opportunities, constraints and trade-offs for legume cultivation for different types of farmers *(Chapter 5)*.

1.6 Study areas and selection of legumes

In Chapter 2, we investigated the variability in yield and response to inputs of soybean in northern Nigeria. Nigeria is the largest producer and consumer of soybean in sub-Saharan Africa and demand continues to grow as source of feed and for human consumption. Production is mainly done by smallholders with an average productivity around 1 t ha^{-1}, way below the yields of around 3 t ha^{-1} achieved on research stations in Nigeria (Tefera, 2011). Soybean could benefit from the use of phosphate (P) fertilizer and rhizobium inoculants, yet, many African countries lack the facilities to produce, store and distribute high quality inoculants (Pulver et al., 1982; Bala et al., 2011). Since the early 1980s, research has therefore focused on breeding soybean (*Glycine max* (L.) Merrill) varieties that can nodulate with rhizobia indigenous to African soils – so-called 'promiscuous' varieties (Sanginga et al., 2000; Giller, 2001). Large-scale testing of these varieties with and without inoculation under farmers' management had not been done before. In Chapter 2, I analysed data from more than 300 farmers trying out these varieties with P-fertilizer and inoculants on their own field, which was collected as part of a dissemination campaign of these technologies in northern Nigeria.

Realizing that understanding where technologies work best does not necessarily lead to adoption of these technologies, Chapters 3 to 5 focus on the co-design, use and farm-level opportunities and constraints for legume technologies for different types of farmers. This part of the study was applied to climbing beans (*Phaseolus vulgaris* L.) in the highlands of Uganda. Beans are an important staple crop in many East African countries. While bush bean varieties have been widely grown for centuries, climbing bean varieties were introduced through a targeted breeding programme in Rwanda since the mid-1980s (Sperling and Muyaneza, 1995; Franke et al., 2016). Through their vertical growth, climbing beans have a better yield potential (up to 4 to 5 tons ha^{-1}), produce more biomass and fix more nitrogen than bush beans (Bliss, 1993; Wortmann, 2001; Ramaekers et al., 2013). Especially in areas of high population pressure and small farm sizes, such as the highland areas of Uganda, climbing beans offers great potential for agricultural intensification. Compared with bush beans, climbing beans require a major change in cropping system: bush beans are mostly grown in intercropping with maize, but climbing beans have a more prolific growth and smother the maize when planted at the same time (unlike at cooler, high elevations in Latin America, where maize and climbing bean intercropping is common (Davis and Garcia, 1983; Clark and Francis, 1985)). Climbing beans are therefore better grown as sole crops, which means that, in land scarce areas, they will likely replace existing crops. Climbing beans also need to be staked, requiring additional labour and capital (Sperling and Muyaneza, 1995; Musoni et al., 2014; Ruganzu et al., 2014). The combination of climbing beans being a new crop, requiring a change in cropping system compared with bush bean and the need for investments in staking material made this legume an interesting example for a co-design process, understanding use and adaptation and exploring its fit at farm level. Moreover, climbing beans can be considered as a 'complex technology': a technology consisting of different components or practices including the climbing bean variety, the use of inputs (manure, mineral fertilizer), staking material and other management practices (plant density, row planting or broadcasting, sole or intercropping, etc.). These components can all be tailored, making it a more interesting example for technology co-design than the more 'simple' introduction of e.g. a new crop variety.

1.7 Thesis outline and research methods

I applied a selection of methods from farming systems analysis (Table 1.1). In all four research chapters, differences in yields and relevance and implications of options for different types of farmers were considered. In Chapters 2 and 4, we analysed on-farm try-outs of soybean and climbing bean, to describe and understand variability in performance. Chapters 3 and 5 relied on participatory methods for the development of relevant options for growing climbing beans on smallholder farms. In Chapter 5 we developed a simple farm-level model to assess the *ex-ante* impact of climbing bean cultivation.

Table 1.1: Selection of methods from farming systems analysis applied in the research chapters of this thesis

	Farm typology	On-farm try-outs	Participatory methods	*Ex-ante* impact
Chapter 2	X	X		
Chapter 3	X		X	
Chapter 4	X	X		
Chapter 5	X		X	X

The research chapters in this thesis can be considered to move along two dimensions: from improving productivity to understanding adoption; and from field to farm level (Fig. 1.1). Chapter 2 focuses on the technical (and economic) potential to improve productivity at field level. The subsequent chapters increasingly contribute to the understanding of adoption of legume technologies. Chapter 3 is a combination of the search for options that can improve productivity at field level, while taking into account socio-economic factors that typically constrain adoption and farm-level considerations that may influence the relevance of technologies. In Chapter 4, understanding the reasons for use and adaptation of the co-designed options comprised a stronger focus on farm-level considerations, while Chapter 5 explicitly focuses on farm-level opportunities and constraints.

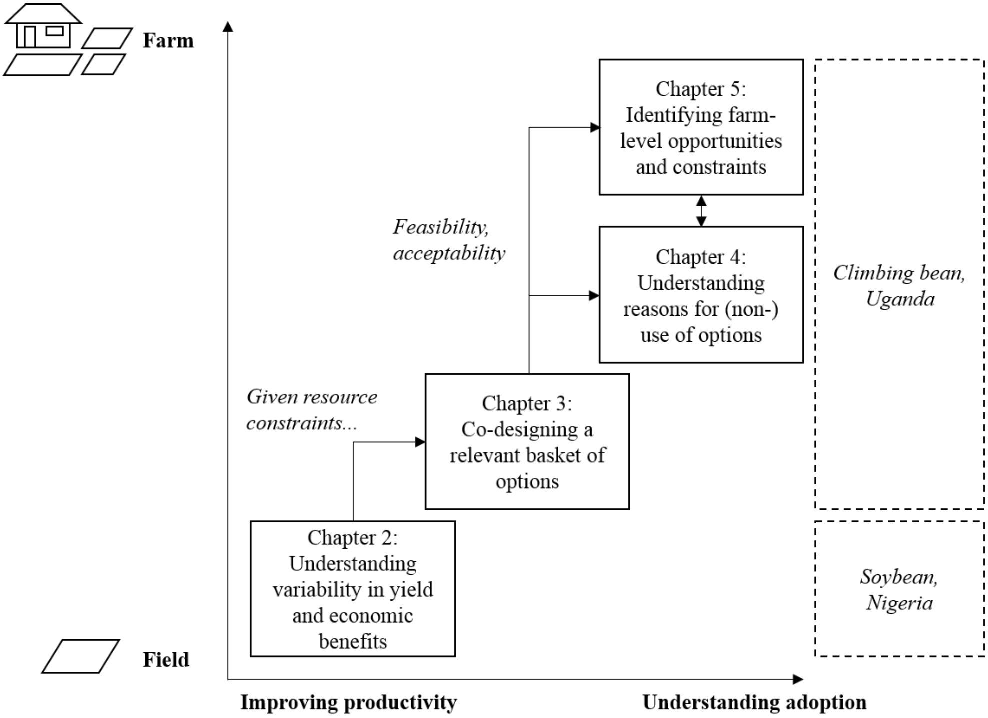


Fig. 1.1: Outline of the thesis, and relative position of the chapters in terms of scale (field to farm level) and adoption process (from technology development to adoption)

In a final Chapter 6, the outcomes of the four research chapters are integrated and discussed. This chapter considers to what extent we managed to understand variability and how variability influences the potential to develop recommendation domains. It also addresses the relation between the co-design process and the adoption of technologies, and the potential to include users' perspectives in large-scale dissemination projects.

Chapter 2

Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria

This chapter is published as:
Ronner, E., Franke, A.C., Vanlauwe, B., Dianda, M., Edeh, E., Ukem, B., Bala, A., Van Heerwaarden, J., Giller, K.E., 2016, Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria. Field Crops Research 186, 133-145.

Abstract

Soybean yields could benefit from the use of improved varieties, phosphate-fertilizer and rhizobium inoculants. In this study we evaluated the results of widespread testing of promiscuous soybean varieties with four treatments: no inputs (control); SSP fertilizer (P); inoculants (I) and SSP plus inoculants (P+I) among smallholder farmers in northern Nigeria in 2011 and 2012. We observed a strong response to both P and I, which significantly increased grain yields by 452 and 447 kg ha^{-1} respectively. The additive effect of P+I (777 kg ha^{-1}) resulted in the best average yields. Variability in yield among farms was large, which had implications for the benefits for individual farmers. Moreover, although the yield response to P and I was similar, I was more profitable due to its low cost. Only 16% of the variability in control yields could be explained by plant establishment, days to first weeding, percentage sand and soil exchangeable magnesium. Between 42% and 61% of variability in response to P and/or I could be explained by variables including year, farm size, plant establishment, total rainfall and pH. The predictive value of these variables was limited, however, with cross-validation R^2 decreasing to about 15% for the prediction between Local Government Areas and 10% between years. Implications for future research include our conclusion that averages of performance of technologies tell little about the adoption potential for individual farmers. We also conclude that a strong agronomic and economic case exists for the use of inoculants with promiscuous soybean, requiring efforts to improve the availability of good quality inoculants in Africa.

Keywords: *Bradyrhizobium*, smallholder farmers, sustainable intensification, West Africa

1. Introduction

The population of sub-Saharan Africa is projected to double in the next 40 years (Cleland, 2013) and increases in food production are much needed (FAO, 2014a; World Bank, 2014). As the potential to expand agricultural land is limited in many areas with high population densities, sustainable intensification of agricultural production is crucial (Pretty et al., 2011; Garnett et al., 2013; Vanlauwe et al., 2014b). A potential pathway for sustainable intensification is the integration of grain legumes in farming systems (Giller and Cadisch, 1995; Peoples et al., 1995). Legumes have the capacity to fix nitrogen from the air in symbiosis with *Rhizobium* bacteria. Legumes can therefore contribute to improved soil fertility in cereal-dominated cropping systems in Africa, including the savannahs of West Africa (Osunde et al., 2003b; Sanginga, 2003; Franke et al., 2008). Legumes can be grown in rotation with other crops, with the additional advantage of reducing the need for N fertilizer for subsequent cereals in the context of Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010). In addition legume rotations assist in reducing pest and disease incidence (Sanginga, 2003; Yusuf et al., 2009), or as inter- or relay crops, often without compromising the yield of the main crop (Baldé et al., 2011). Grain legumes also have important nutritional value in terms of protein, amino acids and micro-nutrients (Gibson and Ferguson, 2008). The short growing period of some legumes ensures availability of food during the hunger period in the middle of the cropping season (Franke et al., 2004; Rubyogo et al., 2010).

Legume yields in African smallholder farming systems are often far below their potential. Numerous studies have shown that legume yields can be enhanced with the use of improved legume varieties (Okogun et al., 2005; Buruchara et al., 2011), phosphate (P) based fertilizers (Weber, 1996; Kamara et al., 2007; Kolawole, 2012), rhizobial inoculants (Sanginga et al., 2000; Osunde et al., 2003a; Thuita et al., 2012), or their combination (Snapp et al., 1998; Ndakidemi et al., 2006). Despite increases in the use of inputs among African smallholders on specific crops in some regions (Sheahan and Barrett, 2014), the use of inputs with legumes remains limited (Chianu et al., 2011; Franke and De Wolf, 2011). Moreover, many African countries lack the facilities to produce, store and distribute high quality inoculants (Pulver et al., 1982; Bala et al., 2011).

Since the early 1980s, research has focused on breeding soybean (*Glycine max* (L.) Merrill) varieties that can nodulate with rhizobia indigenous to African soils – so-called 'promiscuous' varieties (Sanginga et al., 2000; Giller, 2001). A breeding programme was initiated at the International Institute for Tropical Agriculture (IITA) in Nigeria to cross promiscuous soybean varieties of Asian origin with varieties from the USA with greater yield potential and better disease resistance (Kueneman et al., 1984; Pulver et al., 1985). The developed varieties had a greater ability to nodulate without inoculation (Sanginga et al., 2000) and they have been widely adopted in West Africa (Sanginga et al., 2003). Despite this success, more recent studies report yield responses to inoculants in these promiscuous varieties (Osunde et al., 2003a; Thuita et al., 2012). Hence, the need to inoculate promiscuous soybean varieties is still under discussion (Thuita et al., 2012), even more so because previous studies did not involve large scale testing of these varieties with and without inoculation under farmers' management.

Nigeria is the largest producer and consumer of soybean in sub-Saharan Africa. Demand continues to grow both as source of feed for the poultry industry and for human consumption. Production is mainly done by smallholders on farms of less than five ha (ACET, 2013). Average soybean productivity in Nigeria is around 1 t ha^{-1} (three-year average 2011-2013 (FAO, 2014b)), way below the yields of around 3 t ha^{-1} achieved on research stations in Nigeria (Tefera, 2011). Soybean production is mainly constrained by poor soil phosphorus availability (Kamara et al., 2007; Kolawole, 2012), diseases such as soybean rust (Twizeyimana et al., 2008) and moisture stress (Tefera, 2011). Other constraints are the high costs or limited availability of good quality inputs (fertilizer, inoculants, herbicides and pesticides (ACET, 2013)). Although most farmers in Nigeria use fertilizers, application is mostly done to maize and at rates well below what is recommended (Manyong et al., 2001; Sheahan and Barrett, 2014).

Legume yields are determined by the effects of legume genotype (G_L), the rhizobium strain(s) nodulating the legume (G_R), the biophysical environment (E), agronomic management (M) and their interactions, as expressed by the relation (Giller et al., 2013):

$$(G_L * G_R) * E * M$$

Understanding the relation between these variables to enhance legume yields requires analysis of the performance of legume/ rhizobium combinations under a wide range of environments and management decisions.

In this paper we describe the results of the widespread testing of phosphate-based fertilizer (P-fertilizer) and rhizobial inoculants in soybean on farmers' fields in northern Nigeria, with the aim to understand the effects of the different variables in the $(G_L * G_R) * E * M$ relationship on soybean yields and response to input application. We also evaluate the consequences of variability in yield for the distribution of the (economic) benefits of input application. Finally, we explore the ability to predict soybean yields and response to inputs for targeting of technologies based on relevant environmental and management factors.

2. Materials and methods

2.1 Study area

The study was carried out in two states: Kaduna and Kano in northern Nigeria, located between 6°50 and 9°15 East and 9°00 and 12°30 North. Kaduna State was split into two regions (North and South, with the latitude of Kaduna City as the border between North and South) to reflect the high diversity in agroecological conditions and agricultural intensification within the state. Rainfall falls in a single season between May and October. Kano State is the northernmost region with the driest climate (about 800 mm annual rainfall) and the shortest growing season (Table 2.1) and is more densely-settled than Kaduna State. Kaduna South receives about 1400 mm annual rainfall and has the longest growing season, but soils are highly variable and farming tends to be less intensive (e.g. in terms of fertilizer use and use of animal draught power). Erratic rainfall, poor soil fertility and weed infestation generally limit agricultural production in northern Nigeria (Manyong et al., 2001; Sanginga, 2003). Major crops in all three regions are cereals (maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench) and millet (*Pennisetum glaucum* (L.) R. Br.)). Yam (*Dioscorea* spp.) and ginger (*Zingiber officinale* Roscoe) are important next to cereals in Kaduna South (Franke and De Wolf, 2011). Soybean is an emerging crop in northern Nigeria, with about 30% of the households in Kano State to 50% in Kaduna State cultivating soybean in 2010 (Franke and De Wolf, 2011).

Table 2.1: Agro-ecological characteristics of study regions Kano, Kaduna North and Kaduna South in northern Nigeria

	Kano	Kaduna North	Kaduna South
Agro-ecological zone	Northern Guinea/ Sudan savannah	Northern Guinea savannah	Southern Guinea savannah
Dominant soil types	Luvisols	Luvisols	Luvisols
Annual rainfall (mm)	700-850	1100-1150	1400-1450
Mean temperature during growing season (°C)	22	22	22
Length of growing season (d)	135	165	195
Main crops	Rice, maize, sorghum, millet, cowpea, groundnut, vegetables	Soybean, cowpea, maize, sorghum, millet	Sorghum, maize, yam, ginger, sesame, soybean

Source: Franke et al. (2011)

2.2 On-farm try-outs of improved soybean technologies

Around 6,000 households in 2011 and 13,800 households in 2012 participated in a dissemination campaign of improved soybean technologies in Kano, Kaduna North and Kaduna South. In each of these regions, Local Government Areas (LGAs) were selected (Fig. 2.1) based on their potential for soybean cultivation and in consultation with local partners. An LGA typically covered several villages that were managed by one extension agent. Within each village, participating farmers were selected by extension agents based on the farmer's interest in soybean cultivation and the accessibility of the farm (for visibility of the plot and possibility for other farmers to visit the plots, as the try-outs also served as demonstrations).

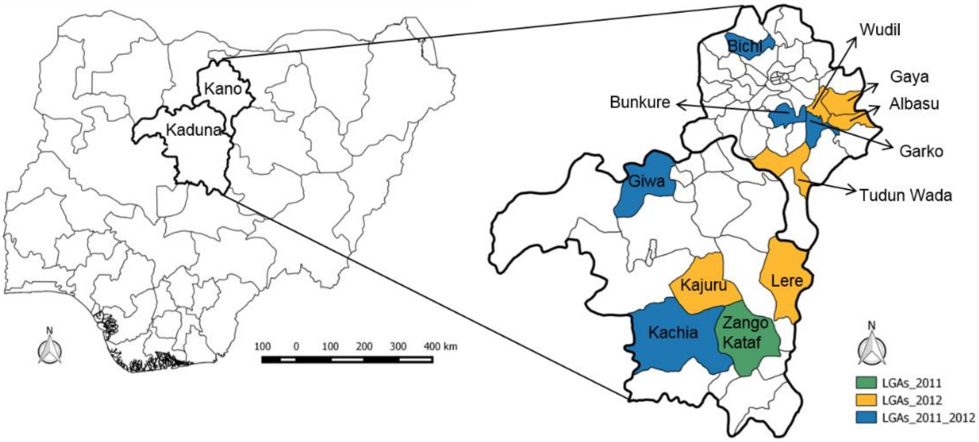


Fig. 2.1: LGAs with try-outs in 2011 and 2012 in northern Nigeria. Different colours represent the year of study.

Farmers were organized in groups of 20-25 people, consisting of one lead farmer (trained directly by the project) and 19-24 satellite farmers (trained by the lead farmer). Each farmer received a package with seed of an improved soybean variety, single super phosphate (SSP) fertilizer and rhizobial inoculant. Farmers tested the package on their own field in a simple, non-replicated try-out whereby each farm formed a replicate. Lead farmers had try-outs measuring 20 × 30 m, with four treatments on sub-plots of 10 × 15 m; satellite farmers had try-outs of 20 × 20 m with four sub-plots of 10 × 10 m. The four treatments were: no inputs (control); SSP only (P); inoculants only (I) and a combination of SSP and inoculants (P+I). Soybean varieties used came from the IITA soybean breeding programme. All were promiscuously-nodulating varieties but they differed in maturity period, potential grain yield and harvest index (Table 2.2). Varieties were targeted to particular regions; hence not all varieties were assessed in all regions.

SSP (18% P_2O_5) was applied at a rate of 20 kg P ha^{-1} at planting. Recommendations were to band the fertilizer 10 cm away from the planting line in a 2-5 cm deep trench, covered after application. Actual application methods may have varied but were not recorded. The inoculant (LEGUMEFiX) contained 10^{10} cells g^{-1} of *Bradyrhizobium japonicum* strain USDA 532c together with a polymer sticker allowing dry inoculation (www.legumetechnology.co.uk). Try-outs were planted by satellite farmers with the help of lead farmers. Lead farmers assisted with the application of inoculants: each farmer group received one sachet of inoculants, which was mixed on-site with the seed at a rate of 4 g kg^{-1}. The seed was sown by individual farmers immediately afterwards. Recommendations included to plant soybean on top of ridges at a spacing of 75 cm between rows and 10 cm between plants with 3 seeds per hill (Kamara et al., 2014). However, reported densities varied from 75 to 90 cm between rows and 5 to 25 cm between plants. Try-outs were planted between mid-June and early August depending on location. Management of the try-outs during the season was done by farmers so timing and number of weedings varied.

Table 2.2: Soybean varieties and their maturity time and group used in try-outs in northern Nigeria in 2011 and 2012

Breeding line	Maturity time (days)	Maturity group	Potential grain yield (t ha^{-1})	On-farm grain yield (t ha^{-1})^3	Target region
TGx 1835-10E	89-92	Early	2.0^1	1.8	Kano
TGx 1987-10F	94	Early	2.2^2	1.7	Kano, Kaduna South
TGx 1935-3F	79-105	Early	1.0 - 3.1^1	1.6	Kano, Kaduna North, Kaduna South
TGx 1987-62F	100-110	Medium	2.2^2	2.1	Kano
TGx 1951-3F	105-110	Medium	1.7 - 2.4^1	1.6	Kano, Kaduna North, Kaduna South
TGx 1955-4F	105-110	Medium	1.4 - 2.6^1	1.6	Kaduna South
TGx 1904-6F	104-114	Medium	2.5 - 2.7^1	1.9	Kano, Kaduna North, Kaduna South
TGx 1945-1F	105-115	Medium	1.2 - 2.6^1	2.0	Kano
TGx 1448-2E	115-117	Late	2.4 - 2.5^1	2.1	Kano, Kaduna North, Kaduna South

[1] *Grain yields with 100 kg ha^{-1} of NPK (15:15:15) and 50 kg ha^{-1} of triple super phosphate, no rhizobial inoculants.* Source: Tefera (2011).

[2] *Grain yields with 100 kg ha^{-1} of NPK (15:15:15), no rhizobial inoculants.* Source: Tefera et al. (2009b).

[3] *Grain yields with 20 kg P ha^{-1} applied as SSP fertilizer and inoculated with* Bradyrhizobium japonicum*, as measured in on-farm try-outs in this study.*

2.3 Data collection and analysis

A sub-set of the soybean try-outs was monitored during the growing season (143 try-outs in 2011 and 191 in 2012). This sub-set was based on stratification by LGA, gender and type of farmer (lead or satellite farmer) and further selection by extension agents (avoiding fields with major problems such as destruction by livestock or flooding). Information on planting, weeding and harvest dates; conditions of the field (perceived soil fertility, drainage) and cropping history of the field was gathered in a 'field book'. The field book also contained questions on socio-economic characteristics of the household and an evaluation of the different treatments in the try-out by the farmer. Farmers filled in the field book with the help of extension agents. At the end of the season, farmers harvested the plots separately and the grain was kept until weighed and recorded by extension agents. Soil samples (0-15 cm depth) were taken at the establishment of the try-outs at a sub-sample of farms and LGAs (58 farms in 2011 and 43 farms in 2012).

The data set was cleaned to include only try-outs where grain yields of all four treatments were reported. From this dataset some try-outs were discarded due to irregularities in data collection (e.g. unclear treatment codes, unclear conversion of units). This resulted in a cleaned set of 63 try-outs in 2011 and 93 in 2012 (44% and 48% of the total try-outs monitored). Soybean grain yields were reported as shelled yields, with the exception of three try-outs. The unshelled yields of these three try-outs were converted to shelled yields through a conversion factor of 0.7 (Van den Brand, 2011), to allow direct comparison with shelled yields. Grain yields represent air-dry weight (11-14% moisture). Soils were analysed for pH (H2O, 1:1 soil to H2O ratio), organic C (Walkley-Black), total N (Kjeldahl), P Olsen (2011) and P Mehlich (2012), and exchangeable K, Ca and Mg (IITA, 1982). P was only assessed as P Olsen by specific request in 2011, while assessment in 2012 was done according to the standard laboratory procedure (P Mehlich). A few farmers applied organic fertilizer across all plots (type of organic fertilizer indicated, quantities not measured). For other farmers the distinction between ‘not applied’ and ‘missing data’ could not be made. As there was no significant difference in yield between farmers who did and did not record organic fertilizer application, nor an interaction with the response to treatments, this variable was excluded from further analyses. Daily rainfall data was obtained from NASA’s Tropical Rainfall Measuring Mission (TRMM). Estimates were obtained for 150 days from June 16th in 2011 and 2012. Days with less than 0.5 mm of rain were designated as dry days. A drought period was defined as 7 or more consecutive dry days. An indicator variable was created for the occurrence of one or more drought periods.

An economic analysis of the profitability of an investment in SSP and/or inoculants was carried out by deducting the costs of SSP fertilizer and inoculants from the additional yield obtained with these inputs compared with the control yield. Prices of SSP and soybean were obtained from a market survey carried out in the study area in 2013 and were set at 0.60 US\$ kg^{-1} for soybean and 126 US\$ ha^{-1} for SSP (20 kg P ha^{-1}). Inoculants were not available on the market at the time of the study and were estimated to cost 5 US\$ ha^{-1}. Labour requirements for the application of SSP were based on Van Heemst et al. (1981) and set at 35 hours ha^{-1}. Casual labour in the area cost 300-400 Naira at the time of study, or about 2.25 US\$ (1 US\$ is 155 Naira). With a working day of 8 hours labour costs for application of SSP were 10 US\$ ha^{-1}. Additional labour for the application of inoculants was considered negligible and excluded. The benefit cost ratio for the investment in SSP and/or inoculants was calculated as the difference in grain yield between the control and P and/or I yield, multiplied by the price of soybean and divided by the costs of inputs and additional labour. A sensitivity analysis was carried out whereby input and output prices were varied by 50%, reflecting variations in market prices found in northern Nigeria (Berkhout, 2009; Franke et al., 2010).

2.4 Statistical analyses

Statistical analyses were performed in R version 3.1.2 (R Core Team 2014). The effects of year, region, variety maturity group, P, I and their interactions on yield were estimated with a linear mixed model, taking each farm as a random block term. Yield was square root transformed to ensure homoscedasticity of residuals. Farms with plot-level residuals larger than three standard deviations (2 farms in 2011 and 9 in 2012) were excluded.

Mean yields and input responses per farm were estimated by fitting a linear model with a farm main effect and interaction between farm and P and I, ignoring any interaction between P and I. The use of model-based means instead of observed plot values was deemed preferable for subsequent analysis of variability since it accounts for some of the variation due to experimental error.

We studied the relation between treatment yields and different environmental and management variables measured in the field books. For this analysis, we only included try-outs for which soil data were present (85 farms). In addition, try-outs with missing values for any of the other relevant variables (Table 2.3) had to be left out. Finally, try-outs with outliers of more than four standard deviations from the mean for any of the variables were also removed. This resulted in a total of 57 try-outs (37% of the try-outs with four treatments), distributed over 6 LGAs, for which data on all relevant variables were available. A mixed model was used to test for potential bias caused by this selection. No significant difference in yield or response to P between selected and non-selected farms was found, but there was a moderate effect of I (140 kg, P=0.025). A linear mixed model with LGA as random factor was used to model control yield, response to P, response to I and response to P+I as a function of the parameters listed in Table 2.3. Soil P could not be included as variable in the analyses due to the different methods used to determine P in 2011 and 2012. We also explored the relation between the, partially correlated, explanatory parameters and yield and input response by redundancy analysis of the residual from the above model with year as the only fixed effect.

A final statistical model was obtained by backward selection of variables using the function *step* in the R package *lmerTest*. The R^2 of this model was defined as the squared correlation between the predicted and observed values and significance, although of limited meaning in a model resulting from variable selection, was calculated by simple linear regression. The predictive value of the model was evaluated by cross validation by dividing the data equally between training and validation sets at the farm or LGA level. The training set was used to obtain parameter estimates for all variables in the final model, which were then used to predict economic benefit in the validation sets. Cross validation R^2 was calculated as the squared average Pearson correlation (R) between predicted and observed values over 1000 random subsets.

Table 2.3: Variables included in redundancy analysis (RDA) and mixed model, and abbreviations used in the RDA

Variable and description	Acronym in RDA	Variable and description	Acronym in RDA
Estimated control yield (kg ha^{-1})	Cont_yield	% organic matter	OC
Estimated response to P (kg ha^{-1})	P_res	% N	N
Estimated response to I (kg ha^{-1})	I_res	K (cmol+ kg^{-1})	K
Response to P+I (kg ha^{-1})	P+I_res	Ca (cmol+ kg^{-1})	Ca
Planting day	Planting_day	Mg (cmol+ kg^{-1})	Mg
Number of weedings	No_weedings	ECEC (cmol+ kg^{-1})	ECEC
Number of days between planting and first weeding	Weeding_day	Percentage sand	Sand
Number of days between planting and harvest	Harvest_day	Percentage clay	Clay
Plant establishment (%)	Plant_estab	Farm size (ha)	Farm_size
Plant density	Plant_density	Household hired labour: yes (1) or no (0)	Hired_labour
Cumulative rainfall from 150 days after June 16th (first planting date) in 2011 and 2012 (mm)	Tot_rain	Household members worked on other people's fields : yes (1) or no (0)	Sold_labour
Number of drought days (<0.5 mm rainfall)	Drought_days	Gender of farmer: male (1) or female (0)	Gender
Drought period (7 or more days without rainfall)	Drought	Age of farmer	Age
pH (H_2O)	pH		

Significance of R was determined based on the 5% lower tail of the generated distribution. The ability to predict across years was also evaluated, where R^2 was calculated as the squared average R for prediction of 2012 data from 2011 and vice versa. Prediction was deemed significant if the lowest value of P for the two tests of positive correlation was 0.025 (i.e. Bonferroni correction for two tests at α=0.05).

3. Results

3.1 Soil properties

Soils of Kano State contained a larger percentage of sand than those of Kaduna State, and contained smaller percentages of organic C and N (Table 2.4). In all three regions, average concentrations of available P, as well as effective cation exchange capacity were low to very low (Hazelton and Murphy, 2007; Mallarino et al., 2013). Exchangeable K was optimal in most sites, and low in Garko and Kajuru (Mallarino et al., 2013). Most soils had a pH around 6; only the soils in Kajuru in Kaduna State were strongly acidic (pH 4.8).

3.2 Soybean grain yields

Both P and I had a strong and highly significant (P<1e-5) effect on grain yield, increasing yield by 452 and 447 kg ha^{-1} respectively (Table 2.5). The interaction between the response to P and I was slightly negative (122 kg, P=0.026). Variety maturity group had no significant effect on yield and no interaction with either P or I. Yield was 25 kg higher in 2012 (P=0.015) while response to I was 53 kg less in 2012 than in 2011, causing a significant interaction between year and I application (P<0.001). The highly significant response to inoculant is remarkable considering that all varieties used in the try-outs were bred for promiscuity.

Yields differed per region (P=0.015): average yields were larger in Kaduna North than in Kano State and Kaduna South (Table 2.5). There were no interactions between region and variety or input application. The lack of interaction between region and input application is explained by the large variation within regions, and interactions between LGA and input application were significant (data not presented). In Kano State, for instance, Bichi and Bunkure LGA had relatively small, and Gaya and Wudil had relatively large yields. Differences within Kaduna South were even larger: yields in Kachia LGA were overall about four to five times smaller than in Kajuru and Zango Kataf.

3.3 Variability in yields and response to SSP and inoculants

While the best average yields were achieved with the combination of P+I, the variability in yields between individual farms was large (Fig. 2.2). Yields in the control plots ranged from 250 kg ha^{-1} to 2500 kg ha^{-1}. On almost all farms, yields increased with P and/or I; only a few farms had yields with P and/or I below the 1:1 line. The response to these inputs varied widely, however, with yields of P+I for example ranging from 250 kg ha^{-1} to more than 4000 kg ha^{-1}.

Table 2.4: Average soil properties of fields with try-outs in Local Government Areas (LGA) of Kano, Kaduna North and Kaduna South

Region LGA	n	pH (H_2O)	OC (g kg^{-1})	Total N (g kg^{-1})	P Olsen (mg kg^{-1}), 2011*	P Mehlich (mg kg^{-1}), 2012*	Exch. K cmol+ kg^{-1})	Exch. Ca (cmol+ kg^{-1})	Exch. Mg (cmol+ kg^{-1})	ECEC (cmol+ kg^{-1})	% Sand	% Silt	% Clay
Kano	*20*	*5.92*	*4.37*	*0.40*	*4.39*	*8.30*	*0.22*	*2.03*	*0.71*	*3.34*	*74*	*14*	*12*
Bunkure	6	6.50	5.48	0.51	6.69	n.a.	0.28	2.30	0.85	3.56	69	18	13
Garko	14	5.66	3.90	0.36	2.42	8.30	0.19	1.91	0.66	3.24	76	12	12
Kaduna North	*16*	*5.99*	*8.65*	*0.74*	*2.30*	*3.90*	*0.21*	*2.18*	*0.84*	*3.37*	*45*	*37*	*17*
Giwa	16	5.99	8.65	0.74	2.30	3.90	0.21	2.18	0.84	3.37	45	37	17
Kaduna South	*61*	*5.65*	*9.45*	*0.85*	*2.90*	*10.21*	*0.26*	*2.21*	*0.65*	*3.52*	*61*	*19*	*20*
Kachia	18	5.52	9.59	1.00	3.10	15.71	0.23	1.76	0.55	2.83	66	14	20
Kajuru	12	4.79	n.a.	0.65	n.a.	4.87	0.17	2.21	0.74	4.09	52	28	20
Lere	16	6.30	10.79	0.84	n.a.	14.64	0.33	3.34	0.91	4.96	61	23	17
Zango Kataf	15	5.84	7.95	0.85	2.69	n.a.	0.28	1.63	0.43	2.46	57	19	23
Total/Mean	97	5.76	8.09	0.74	3.12	9.17	0.24	2.17	0.69	3.46	61	21	18
Significance (*P*-values)													
Region		ns	<0.001	<0.001	ns	ns	ns	ns	ns	ns	<0.001	<0.001	<0.001
LGA		<0.001	<0.001	<0.001	ns	ns	ns	0.005	<0.001	0.001	<0.001	<0.001	<0.001

** P analysed with Olsen in 2011 and Mehlich in 2012.*

OC = organic carbon, ECEC = effective cation exchange capacity, n.a. = not available.

Table 2.5: Average soybean grain yields (kg ha^{-1}) for control (no inputs), P, I and P+I treatments in on farm try-outs in regions and LGAs of northern Nigeria, 2011 and 2012. P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*. LSDs were calculated based on the transformed yield data (values between brackets).

	N	Control	P	I	P+I
Total	145	968 *(31.1)*	1420 *(37.7)*	1415 *(37.6)*	1745 *(41.8)*
Max LSD			*(1.0)*		
Year					
2011	61	902 *(30.0)*	1406 *(37.5)*	1380 *(37.2)*	1833 *(42.8)*
2012	84	1035 *(32.2)*	1423 *(37.7)*	1460 *(38.2)*	1660 *(40.7)*
Max LSD year			*(4.3)*		
Region/ LGA					
Kano State	64	782 *(28.0)*	1251 *(35.4)*	1104 *(33.2)*	1590 *(39.9)*
Albasu	1	2330	2697	2782	3024
Bichi	7	609	1164	945	1356
Bunkure	20	586	1049	952	1467
Garko	16	808	1323	1181	1686
Gaya	3	1697	1623	1749	2017
Tudun Wada	8	956	1326	961	1498
Wudil	9	1119	1378	1376	1716
Kaduna North	17	1265 *(35.6)*	1755 *(43.9)*	1924 *(41.9)*	2108 *(45.9)*
Giwa	17	1357	1890	2085	2444
Kaduna South	64	887 *(29.8)*	1279 *(35.8)*	1278 *(35.7)*	1565 *(39.6)*
Kachia	20	325	500	472	643
Kajuru	14	1373	2106	1982	2428
Lere	15	822	973	969	1248
Zango Kataf	15	1602	2411	2603	2917
Max LSD region			*(6.0)*		

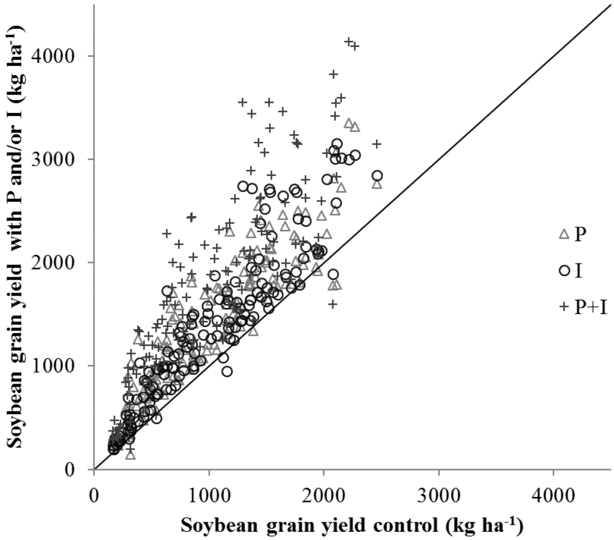


Fig. 2.2: Soybean grain yields control (kg ha^{-1}) and response to P, I and P+I for individual farms in northern Nigeria (2011 and 2012). P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

Yields on farms with the smallest grain yields of around 250 kg ha^{-1} did not respond well to the application of P and/or I. All these farms, in the bottom left-hand corner of Fig. 2.2, were located in Kachia LGA.

Small absolute responses to P and/or I were most frequently found on farms with control yields between 250 kg ha^{-1} and 500 kg ha^{-1} (Fig. 2.3A). Farms with control yields between 500 kg ha^{-1} and 1500 kg ha^{-1} had the largest response. For each level of control yield, however, there were also farms with a minimal response. The differences in response were again related to location: LGAs with better control yields had better responses, and LGAs with small control yields (e.g. Kachia) had only minor responses to treatments. Responses varied less between farms within each LGA. The relative response to treatments (Fig. 2.3B) showed the same pattern of farms with control yields of less than 500 kg ha^{-1} having the largest relative increase in yield with P and/or I. As the control yield increased, the relative response diminished. Although some of the farms with a control yield of less than 250 kg ha^{-1} gave double the grain yield with the application of P+I, the absolute increase remained small.

3.4 Distribution of responses to SSP and inoculants

Not all farmers benefitted to the same extent from the application of P and/or I (Figs. 2.2 and 2.3). Investing in fertilizer or inoculants comes with a risk, and farmers will be reluctant to apply inputs if there is a considerable chance of a weak response.

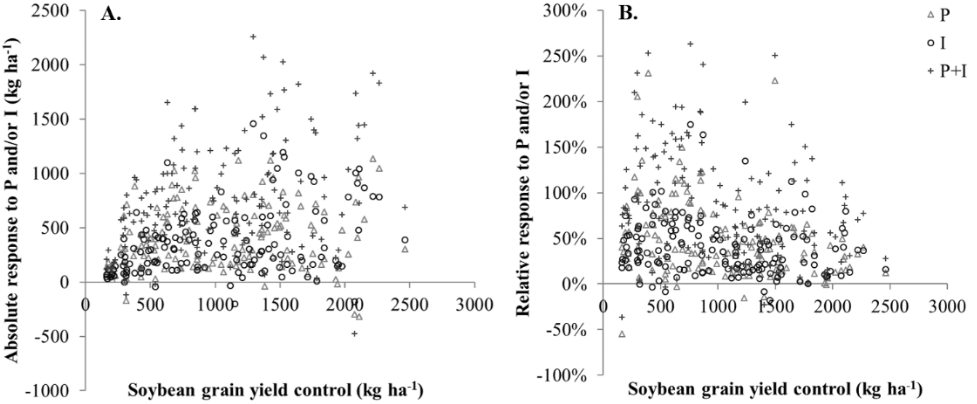


Fig. 2.3A&B: Estimated soybean grain yields of control (no inputs) (kg ha^{-1}) and response to P, I and P+I for individual farms in northern Nigeria (2011 and 2012) as absolute response (kg ha^{-1}; yield of P and/or I minus control yield) (A); and relative response (%; yield of P and/or I minus control yield, divided by control yield) (B). P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

We considered this risk and expressed it as the probability of achieving a certain absolute or relative response to P and/or I compared with the control yield.

In absolute terms, more than 95% of the farmers saw a positive response to the application of P and/or I compared with the control. Half of the farmers increased their grain yield by about 318 kg ha^{-1} or more with P, by 280 kg ha^{-1} or more with I and by 690 kg ha^{-1} or more with P+I (Fig. 2.4A). Gains of 1000 kg ha^{-1} or more were achieved by only 3% of the farmers with P, by 6% with I and by 26% with P+I. To judge if a technology works, farmers need to see a substantial increase in yield in the field. An increase in grain yield of at least 10% would be needed for the effect of a given treatment to be visible for farmers. A 10% increase occurred on a large majority of farms: about 88% achieved an increase of >10% with P or I and 94% with P+I (Fig. 2.4B). Half of the farms had an increase in yield of about 37% with P or I, and of 79% with P+I. About 10% of the farmers doubled their grain yield with the application of P, 3% doubled their yield with I and 37% with P+I. As indicated in Fig. 2.3B, farmers with smaller control yields had the largest relative increases, although their absolute increases were small.

The use of inputs is only attractive to farmers when the benefits in yield outweigh the additional input and labour costs. Risk can therefore also be expressed as the probability of achieving a certain economic benefit from the application of P and/or I compared with the control yield (Fig. 2.4C).

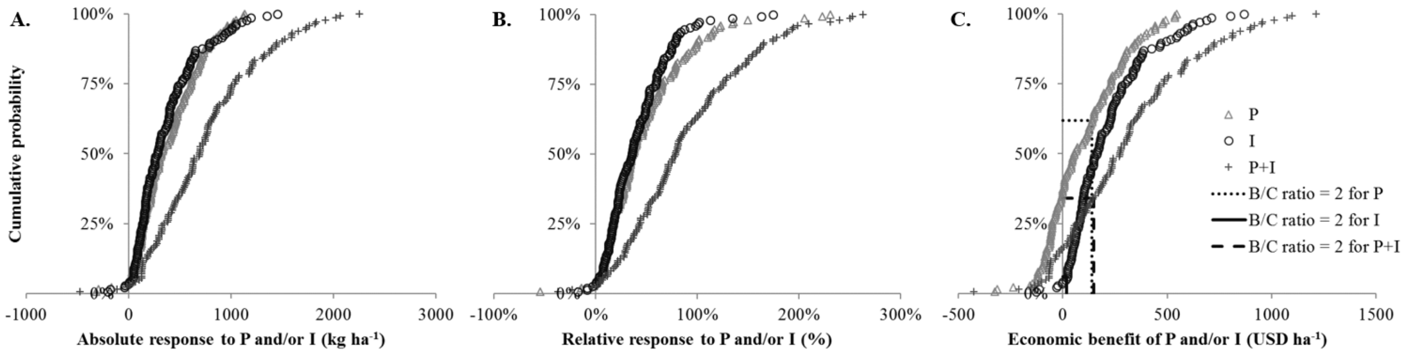


Fig. 2.4A, B&C: Cumulative probability of estimated absolute response (kg ha^{-1}) (A); relative response (%) (B) and economic benefits (additional yield minus relevant input costs, US$ ha^{-1}) (C) of P and/or I compared with control. Dashed lines in Fig. C represent a benefit/cost (B/C) ratio of 2 for the application of P and/or I. P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

Looking at the economic benefits changes the picture: although over 95% of the farmers increased their yield with the application of P, only about 60% achieved an economic benefit (i.e. marginal values larger than marginal costs), as the cost of SSP fertilizer application including labour is large. Inoculant application is relatively cheap, and almost all farmers (about 95%) achieved an economic benefit from its application. Because yields for the combination of P+I were larger than for P or I only, this combination was also economically beneficial for 83% of the farmers.

For the adoption of technologies, however, the break-even point is often not sufficiently attractive. A benefit cost ratio (B/C) of 2:1 is generally considered necessary to lead to adoption. This ratio was still achieved by almost all farmers who applied inoculants (95%). For P, however, only about 40% of the farmers achieved a B/C ratio of 2, so again much less than the 60% of farmers who broke even. For P+I this ratio was achieved by about two-third of the farmers.

The distribution of economic benefits depends greatly on fluctuations in input and output prices, as assessed in a sensitivity analysis (Table 2.6).

Table 2.6: Sensitivity analysis of the economic benefits of P and/or I under fluctuation of input and output prices as percentage of farmers breaking even or achieving benefit/cost (B/C) ratio of 2. P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

Variable	Fluctuation	% of farmers breaking even			% of farmers with B/C = 2		
		P	I	P+I	P	I	P+I
Average market prices		62	95	83	38	94	66
Soybean grain price	- 50%	39	95	66	6	94	31
	+ 50%	73	96	88	51	95	78
SSP and inoculant price	- 50%	82	96	92	58	95	82
	+ 50%	49	95	74	21	95	50
Labour price*	- 50%	65	-	83	41	-	66
	+ 50%	61	-	83	36	-	64

** Additional labour for the application of inoculants was considered negligible and therefore not used in the calculation of economic benefits.*

Fluctuations in the price of soybean grain or SSP fertilizer considerably affected the economic benefits achieved with P. With a 50% decrease in soybean grain price, the percentage of farmers breaking even decreased from about 60% to 40%, and only 6% of the farmers achieved a B/C ratio of 2. Also for P+I the percentage of farmers achieving a B/C ratio of 2 decreased to only one-third. Considering the need of many smallholders to sell their grain shortly after harvest in search for cash, this scenario again shows the financial risk associated with the application of fertilizer. On the other hand, with a 50% increase in soybean price, almost 90% of the farmers broke even with P+I, and almost 80% achieved a B/C ratio of 2. A 50% decrease in the price of SSP fertilizer also had a large effect: the percentage of farmers breaking even with the application of P increased to more than 80%, and almost 60% of the farmers had a B/C ratio of 2. For P+I, more than 90% would break even and more than 80% would have a B/C ratio of 2. The economic benefits achieved with the application of I were very stable under price fluctuations due to the small costs for inoculants. Fluctuations in labour prices only had a minor influence on profitability, as the additional labour costs for fertilizer application constitute a small part of the total costs.

3.5 Understanding variability in yield and response to SSP and inoculants

In the remainder of this study we explore the factors influencing the variability in yields to understand where the technologies work best, and to what extent we could use this information to target technologies to the farmers that will achieve the greatest benefits from them.

A redundancy analysis of the environmental and management factors, to identify the relation between these factors and control yield and response to P and/or I, showed that the responses to P and/or I were all related to the first redundancy axis (Fig. 2.5). Variables that were positively correlated with this axis were farm size (the larger the farm, the stronger the response), the number of weedings and households that sold labour (households with family members working on other people's fields had better yields). Variables negatively correlated with the response to P and/or I were pH, percentage OC and N. These soil fertility parameters were correlated with each other as well. Total rainfall, the number of drought days and planting day were also correlated, and negatively related with the responses. Control yields were related to the second axis and showed no relation with the response to P and/or I. The lack of relation between control yields and responses is in contrast to the relation observed in Fig. 2.3A, and is the result of the correction for location in the redundancy analysis: responses differed between LGAs, but not within LGAs. Control yields were related with plant establishment, and also with a number of soil fertility parameters (K, Mg and Ca) which were again related with each other. Harvest day had a negative relationship with control yields.

A mixed model tested which environmental and management factors had a significant effect on control yield and the response to P and/or I. Control yields were positively related with plant establishment, and this relationship was highly significant (Table 2.7). Control yields were also positively related to the number of days to first weeding, the percentage of sand and Mg.

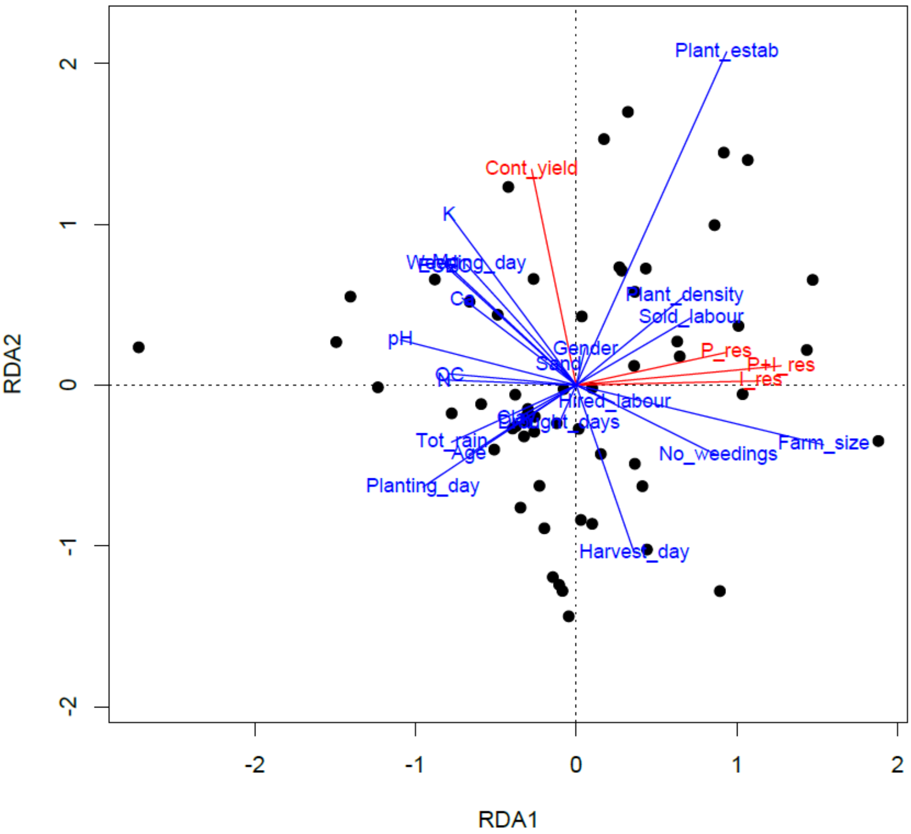


Fig. 2.5: Redundancy analysis (RDA) of control yield and response to P and/or I with location as random, and year as fixed effect. Abbreviations of explanatory variables are given in Table 2.3. P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

Year, farm size, planting day, total rainfall and pH all had significant effects on the response to P and/or I. Year had a negative effect, with yields in 2012 smaller than in 2011. Larger farms had better responses to the treatments. Remarkably, total rainfall was negatively related with the response to P, and positively with P+I. Finally, pH had a negative, significant relation with the response to P and/or I.

The R^2 for the percentage variability in control yields and response to P and/or I explained by environmental and management factors ranged from 16% for the control yield to 61% for the response to P+I. Ideally, by understanding variability in yields, we would be able to predict the performance of P and I on new farms, and hence to target our technology interventions. We could use the relevant variables from the model to select farmers who would be expected to benefit most from the application of P and/or I.

Table 2.7: Explanatory variables for variability in control yield and response to P and/or I, R^2 of the model for the whole dataset (the value for the training model is given in brackets for direct comparison with the cross-validation R^2s) and results of cross-validation (CV) of the model between fields, LGAs and years (* indicates values significantly different from 0). P = 20 kg P ha^{-1} applied as SSP fertilizer; I = seed inoculated with *Bradyrhizobium japonicum*.

Treatment (yield) / Explanatory variables	Effect pos (+) or neg (-)	*P*-value	R^2	CV1 (fields)	CV2 (LGA)	CV3 (year)
Control (1030 kg ha^{-1})						
Plant establishment	+	8.09e-05	0.16* (0.80*)	0.13*	0.12	0.24*
Weeding day	+	0.03766				
% Sand	+	0.01562				
Mg	+	0.00227				
Response P (382 kg ha^{-1})						
Year	-	0.00019	0.45* (0.56*)	0. 25*	0.02	0.05*
Farm size	+	0.00773				
Planting day	+	0.03529				
Total rainfall	-	0.00015				
Plant density	-	0.03957				
pH	-	0.03405				
Response I (432 kg ha^{-1})						
Year	-	0.037854	0.42* (0.58*)	0.11*	0.11*	0.08*
Farm size	+	0.009007				
Plant establishment	+	0.025225				
Number of weedings	+	0.029292				
pH	-	0.015017				
Response P + I (815 kg ha^{-1})						
Year	-	0.000592	0.61* (0.70*)	0. 47*	0.06	0.01
Farm size	+	0.000056				
Plant establishment	+	0.015277				
Planting day	-	0.036012				
Total rainfall	+	0.017109				
pH	-	0.002006				

Cross-validation of the model outcomes showed, however, that the predictive value of these variables was much smaller than the percentage of variability that could be explained (to be compared with R^2 values of the training model) (Table 2.7). We first based the cross-validation on a random sub-set of farms from the dataset. This gave a reasonable prediction, meaning that if we would expand the work among a very similar group of farmers we could do a reasonable estimate of where the technologies would work best. However, when results of a sub-set of LGAs were used to predict yields in other LGAs, the cross-validation R^2

drastically decreased. The result was again worse for the prediction between years. LGA and year were partly confounded, however, as 2011 and 2012 included different LGAs and this could not be corrected for due to the limited overlap between LGAs in both years. Hence, even though the variability in yields and responses to P and/or I could be explained reasonably well with the variables included in the analysis, the predictive value of these variables across seasons and geographical areas (LGAs) was limited.

4. Discussion

4.1 Response to SSP fertilizer and inoculants

Soybean varieties included in this study were bred for promiscuity, yet we observed widespread yield responses to inoculation among all varieties. This is in contrast to previous studies in Nigeria which reported no significant increase in grain yields of these varieties with inoculation (Okogun and Sanginga, 2003; Osunde et al., 2003a; Okogun et al., 2005). Some authors reported a significant increase, however, in the number of nodules (Okogun and Sanginga, 2003; Osunde et al., 2003a) or biomass (Osunde et al., 2003a; Pule-Meulenberg et al., 2011; Thuita et al., 2012).

A large majority of farmers benefitted from the application of inoculants in soybean, in agronomic (Fig. 2.4A) as well as economic terms (Fig. 2.4C). Inoculation therefore is effective in increasing soybean yields with little financial risk, provided good quality inoculants are available to farmers. Availability of inoculants in rural areas remains a key constraint to the use of inoculants in much of sub-Saharan Africa, although there is commercial production in Kenya and South Africa and semi-commercial production in Zimbabwe with extensive distribution to farmers in several countries.

The yield response to SSP was similar to the yield response to inoculation, but the use of inoculants was economically more attractive. SSP applied alone was barely profitable, and farmers would be better off applying SSP together with inoculants as the combination was profitable for a large majority of farmers (Fig. 2.4C). Advice to farmers could be to start with inoculants, and to add SSP when additional capital is available. A stepwise process for the introduction of new technologies has been suggested with increasing requirements in terms of capital, risk and complexity, but also with increasing productivity and profitability (Byerlee and De Polanco, 1986; Aune and Bationo, 2008; Vanlauwe et al., 2010). Frequent cultivation of soybean without P-fertilizer, however, will exhaust soil P reserves, especially considering the already poor soil availability of P in northern Nigeria (Table 2.4) (Okogun et al., 2005; Kamara et al., 2007; Franke et al., 2010). Next to direct effects of P on soybean yield, subsequent crops may benefit from the residual effects of P (Janssen et al., 1987; Van der Eijk et al., 2006). With repeated applications, the need for P in subsequent crops will be reduced, enhancing the profitability of P-fertilizer. *Vice versa*, soybean would benefit from

P applied on a previous crop. Soybean is often grown in rotation with maize to which farmers in Nigeria often apply fertilizer (Manyong et al., 2001). As farmers tend to believe legumes can grow well without fertilizer, they may prefer to use fertilizer on maize, although Zingore et al. (2008) found that in some cases application of P-fertilizer on soybean was more profitable than on maize. Such considerations emphasize the need to analyse cropping systems rather than single crops. Given the strong residual effects of soybean through provision of N and suppression of *Striga hermonthica*, often leading to large increases in yield of the subsequent cereal crop (Franke et al., 2006), the overall economic benefits to farmers are likely to be larger still.

Despite the highly significant response overall to SSP and inoculants, responses differed greatly among farms. Only 21 farms out of 145 (14%) had a response to P+I that was within 10% of the mean of 750 kg ha^{-1}. On 10% of the farms the response was (more than) double the mean, while 17% had responses of less than 250 kg ha^{-1} and 2% had a negative response. The presentation of mean yields therefore gives misleading expectations about the adoption potential of technologies, as mean yields hide the risks for individual farmers (Sileshi et al., 2010; Bielders and Gérard, 2014). In addition, the economic analysis revealed that the use of SSP was unattractive for a relatively large proportion of farmers, despite substantial yield responses. Analysing variability in yield, in responses and in the associated economic risk therefore gives a more complete impression of the attractiveness of these technologies.

4.2 Explaining variability

With the variables we measured we could explain a reasonable part (16 to 61%) of the variability, comparable with the results of Bielders and Gérard (2014) who found that environmental and management factors explained 20% of variability in millet yields under similar experimental conditions. The largest differences were found between locations. Try-outs in Kachia clearly had the smallest yields and response to treatments caused by a combination of factors such as late planting and shallow, rocky soils. On these soils, multiple nutrient deficiencies may have caused the soil to be non-responsive (Foli, 2012; Vanlauwe et al., 2014a). In other cases it appears that excessive rainfall is likely to have caused periodic waterlogging. Better control yields were associated with, among other variables, larger soil Mg contents. As concluded from Fig. 2.5, this could indicate better overall soil fertility considering the correlation with other soil fertility parameters. Hence better control yields were found on more fertile soils. In contrast, the response to treatments was negatively related with the combination of pH, OC and N, which could indicate that fields with better soil fertility had smaller responses to the treatments. The negative relationship between pH and response to treatments seems counterintuitive. Closer analysis showed that soils with a pH of between 5 and 6.5 had better responses than soils with higher or lower pH (data not presented). The positive relation between control yields and percentage sand is also counterintuitive, and may have been the result of confounding other variables. Total rainfall had a positive effect on response to P+I, but was negatively associated with the response to P. This is mainly explained by results in Kachia LGA, where yields were smallest but cumulative rainfall largest in both years. Yields in 2012 were smaller than in 2011, perhaps due to less rainfall in 2012 (data not presented).

4.3 Methodological considerations

While we could explain variability reasonably well, a considerable proportion remained unaccounted for. Would we be able to explain a larger part of the variability if we would have collected more detailed data? We take some examples from Western Europe, where detailed data are available. Bakker et al. (2005) found an R^2 of about 0.90 for the relationship between yield data (10 year average of regions in Europe) and soil, climate and economic variables. Variables in their study were all measured at a high aggregation level, not at farm level, and trends in yields over multiple years also poorly correlated with the explanatory variables (R^2 of 0.17 to 0.43). Landau et al. (2000) found an R^2 (adjusted) of 0.26 for the relation between detailed climatic data and yields of wheat trials in the UK, similar to our results. A detailed study on yield differences between farms in a very homogenous environment in the Netherlands explained 80-90% of variability, largely based on management factors (Zachariasse, 1974). The latter suggests that a more detailed approach in a limited number of sites in a more homogenous environment, together with accurate measurements of potential explanatory variables, could give better results. However, during the first rounds of analyses we also found that many of the observed significant relationships between yield and explanatory factors were based on one or two outliers in these explanatory variables which strongly dominated the outcomes. These outliers were subsequently removed in a systematic way (>4 SD from the mean). A systematic and transparent approach of checking the relevance of these observed significant relations and being open about uncertainties rather than stressing the robustness of the outcomes is a necessity to achieve useful results.

Through cross-validation of our model we showed that the predictive value of the variables we measured was limited for targeting of technologies among farmers in new areas or in subsequent seasons. The prediction for a random sub-set of farmers was reasonable, but probably the result of overfitting of the model rather than actual predictive power. If we would be able to improve this power by better understanding the observed variability, farmers could benefit from targeting technologies: the 50% best performing farmers in Fig. 2.4C achieved an average economic benefit of about 550 US\$ ha^{-1} with P+I application, while the bottom half gained only 70 US\$ ha^{-1}. What could be done to better understand variability and improve the predictive power of future studies? First, many of the explanatory variables were confounded, which may lead to misidentification of the true explanatory factors (Bakker et al., 2005). For instance, varieties were confounded with location: varieties were targeted to LGAs where they were expected to perform well, and not all varieties were grown in all LGAs. This made it hard to find differences in performance between varieties, in contrast to e.g. Tefera et al. (2009a). Planting dates were also confounded with location, making it difficult to establish whether late planting reduced yield or if this was just related to, for instance, a later onset of the rains in that location. Second, we could have missed important variables; as reflected on by Bielders and Gérard (2014). Our study could have benefitted from better rainfall data (measured at plot level instead of averages per LGA), soil data (collected on all farms, with standard procedures for analysis across years), and more detailed information on pests, diseases and ‘external events’ such as destruction of crops by livestock, storms, floods or drought.

A better understanding of which variables determine soybean yields would not necessarily allow better targeting. Taking soil samples on all sites and analysing them before the try-outs are sown would be practically impossible. Rainfall cannot be predicted for the next season, so what works in one season may not work in the next. What would be feasible for targeting? Targeting can be thought of at different geographical scales. At higher levels we could make use of agro-ecological zones, and predict areas in which a technology is expected to perform better based on temperature, length of growing season, soils, etc. with the help of remote sensing, GIS and soil maps. This is was the approach taken to target soybean, amongst other legumes, to farmers in northern Nigeria in this study (Franke et al., 2011), and requires relatively little local prior information. As this study shows, however, there is also considerable variability within agro-ecological zones, e.g. related to differences in resource endowment and gender of the farmer (Franke et al., 2016), or soil fertility and management history (Tittonell et al., 2005b; Zingore et al., 2011). We measured a number of agronomic parameters (planting and weeding dates, number of weedings) to explain this variability, but the difficulty with such parameters is that they cannot be predicted among new groups of farmers. To improve the predictive value of the dataset, we could therefore look for proxies for these parameters: delays in planting and weeding are often related to labour or cash constraints, and hence to resource endowment (Tittonell et al., 2007; Pircher et al., 2013). In addition, we found that larger, and presumably wealthier, farms had better responses to treatments, suggesting better crop management by wealthier farmers. Socio-economic profiles of farmers could therefore help in targeting. Collecting such information would be data intensive, but could work well in countries where such profiles are already available (e.g. Rwanda).

Although our results could have benefitted from a more detailed and complete dataset, it should be kept in mind that our study was undertaken in the context of a legume dissemination campaign, with development rather than research as primary aim. Development partners were responsible for much of the sampling strategy and data collection, which inevitably resulted in greater variability in implementation than trials conducted by researchers. The power of this type of work therefore lies in the large number of observations and the realistic context of farming, which helps to understand the variability in performance, economic benefits and related adoption potential of improved soybean technologies.

5. Conclusion

We observed a widespread response to inoculation in soybean varieties that had been bred for promiscuity. Rhizobial inoculation proved to be a cheap way to increase soybean yields with low financial risks. In addition, inoculation made the application of P-fertilizer economically attractive for a large proportion of farmers, unlike the use of P alone. Despite the strong agronomic and economic case for the use of inoculants, the local availability of good quality inoculants in Africa is problematic at present.

The observed variability in yield and responses to technologies, as well as the associated variability in economic benefits, implies that averages of on-farm performance of technologies are of little value to estimate the adoption potential of a technology for individual farmers. Understanding the causes of variability helps to target technologies to groups of farmers who are expected to benefit most. While we could explain a reasonable percentage of the variability in yields observed in our dataset, the potential to use this information to predict the performance of technologies or to target technologies to a new group of farmers remains limited. Spatial models (GIS, remote sensing) and farm typologies may help to improve such targeting.

Acknowledgements

We thank the Bill & Melinda Gates Foundation for funding this research through N2Africa: Putting Nitrogen fixation to work for smallholder farmers in Africa (www.N2Africa.org); a grant to Wageningen University implemented in 11 countries in sub-Saharan Africa. We also thank the farmers, extension officers and dissemination partners (Sasakawa Global 2000, Kaduna State Agricultural Development Project (KADP), Kano Agricultural and Rural Development Authority (KNARDA) and Federal University of Technology, Minna) in northern Nigeria for their cooperation in data collection.

Chapter 3

Co-design of improved climbing bean production practices for smallholder farmers in the highlands of Uganda

This chapter is submitted to Agricultural Systems as:
Ronner, E., Descheemaeker, K., Almekinders, C.J.M., Ebanyat, P., Giller, K.E., (under review), Co-design of improved climbing bean production practices for smallholder farmers in the highlands of Uganda. Agricultural Systems.

Abstract

In this study we evaluate the usefulness of a co-design process to generate a relevant basket of options for climbing bean cultivation for a diversity of farmers. The co-design process consisted of three cycles of demonstration, evaluation and re-design in the eastern and southwestern highlands of Uganda in 2014-2015. Evaluations aimed to distinguish between preferences of farmers in the two areas, and farmers of different gender and socio-economic backgrounds. Farmers, researchers, extension officers and NGO staff re-designed treatments for demonstrations in the next season. Climbing bean yields and evaluation scores varied between seasons and sites. Evaluation scores were not always in line with yields, and reasons for preference revealed that farmers used multiple evaluation criteria next to yield, such as marketability of varieties, availability of inputs and ease of staking methods. The co-design process enriched the basket of options, improved the relevance of options demonstrated and enhanced the understanding of preferences of a diversity of users. Developing options for resource-poor farmers was difficult, however, because they face multiple constraints. The basket of options developed in this study can be applied across the East-African highlands, with an ‘option-by-context’ matrix as a starting point for out-scaling. The study also showed, however, that consistent recommendations about the suitability of technologies for different types of farmers were hard to identify. This highlights the importance of a basket of options with flexible combinations of practices rather than developing narrowly specified technology packages for static farm types.

Keywords: *Phaseolus vulgaris,* legumes, participatory, multi-criteria

1. Introduction

Agronomic research on experimental research stations under optimum management conditions has been successful in improving crop yields under favourable environments (Chambers and Ghildyal, 1985; Darnhofer et al., 2012). Yet the technologies developed often performed poorly on smallholder farmers' fields due to the heterogeneity of soil fertility and crop management. Moreover, adoption was limited as the technologies developed were not suited to the needs, preferences and resource constraints of smallholder farmers (Collinson, 2001; Darnhofer et al., 2012; Vanlauwe et al., 2016). This led to the realisation that a better understanding of the context in which smallholder farming takes place was needed, and that farmers, the users of technologies, needed to be engaged in the technology development process (Chambers et al., 1989; Nagy and Sanders, 1990; Collinson, 2000). The 1980s witnessed the advent of farming systems research and participatory research. These approaches helped to improve researchers' understanding of farming systems, and to identify users' preferences, objectives and constraints for locally suitable technologies (Chambers et al., 1989; Biggs, 1990; Defoer, 2002). Since then, there is increasing attention for the need to move away from blanket recommendations and to search for locally adapted or tailored, best-fit technologies suitable for a diversity of farmers (Giller et al., 2011; Descheemaeker et al., 2016b; Vanlauwe et al., 2016).

Participatory approaches helped to improve researchers' understanding of farming systems, and to identify users' preferences, objectives and constraints for locally suitable technologies (Chambers et al., 1989; Biggs, 1990; Defoer, 2002). Such methods were later criticized, however, for being time-consuming, site-specific and having limited potential for out-scaling (Sumberg et al., 2003; Conroy and Sutherland, 2004). Much technology development therefore still focuses on solutions to problems perceived by researchers, without taking full account of users' perspectives (Sumberg, 2005; Giller et al., 2009; Nelson and Coe, 2014). Approaches are therefore needed that take into account users' perspectives, while still producing results that are useful for a larger group of beneficiaries.

Out-scaling can be facilitated by the use of recommendation domains (Conroy and Sutherland, 2004; Descheemaeker et al., 2016b), which are commonly based on agro-ecology, population density and market access (Wood et al., 1999; Nelson and Coe, 2014; Farrow et al., 2016). Farmers' yields and their potential to apply technologies are also constrained by socio-economic factors, such as poor access to land, labour and capital or higher-level institutional constraints (Feder and Umali, 1993; Sumberg, 2005; Doss, 2006). Socio-economic diversity among farmers therefore also determines the suitability of technologies, which may require tailoring and adaptation given certain resource constraints (Collinson, 2001; Vandeplas et al., 2010).

A conceptual framework that gives practical guidance to the tailoring of technologies is the Describe-Explain-Explore-Design (DEED) cycle (Giller et al., 2011; Descheemaeker et al., 2016b). In the DEED cycle, a range of methods is applied to describe the current system, explain problems and opportunities for improvement, explore the implications and trade-offs of these opportunities and to design relevant options for new cropping or farming systems. Central to the DEED cycle is the co-learning between researchers, farmers and other stakeholders (Descheemaeker et al., 2016b). An iterative application of this cycle in which farmers test the options, provide feedback and are engaged in the re-design of options can help to develop a number of tailored, locally relevant options – together considered a 'basket of options' – for a diversity of farmers (Dogliotti et al., 2014; Falconnier et al., 2017).

In this study, we developed and applied an iterative co-design process – based on the DEED cycle – in the context of a large-scale "research-in-development" project focusing on the dissemination of grain legumes in 11 countries in sub-Saharan Africa. We zoomed in on one of these legumes in Uganda: climbing beans. Climbing beans offer potential for sustainable intensification of farming systems as, compared with the more widely grown bush bean varieties, climbing beans have a larger yield potential (up to 4 to 5 tons ha^{-1}), biomass production and nitrogen-fixing capacity (Bliss, 1993; Wortmann, 2001; Ramaekers et al., 2013). Improved varieties of climbing bean were introduced in Rwanda in the 1980s (Sperling and Muyaneza, 1995) and spread to neighbouring countries including Uganda. In parts of southwestern Uganda climbing beans are now widely grown, but in other areas they are still relatively new. Inclusion of climbing beans on the farm requires a change in cropping system (from maize + bush bean intercropping to sole cropping of climbing beans), and requires additional investments in staking material (Ronner et al., 2017). Climbing beans can be seen as a 'complex' technology, consisting of multiple components/ practices such as variety use, inputs, staking and other management practices. Given the required changes in cropping system and possible variation in the combination of practices, climbing beans make an interesting case for the application of a co-design process and the development of options for farmers with different opportunities and constraints.

The objectives of this study were to evaluate the usefulness of a co-design process in generating a relevant basket of options for climbing bean cultivation for a diversity of farmers, and to develop an out-scaling tool for these options. We hypothesized that the co-design process would lead to options that could not have been developed by either farmers or researchers alone, and to relevant options for different types of farmers given certain resource constraints. We first describe the co-design process, consisting of three cycles of demonstration, evaluation and re-design of practices. Next, we focus on options for different types of farmers. Finally, we present the basket of options and out-scaling tool that resulted from the co-design process.

2. Methodology

2.1 Study areas

The study was conducted in Kapchorwa District in eastern Uganda, located between 34.30° and 34.55° East and 1.18° and 1.50° North, and Kabale and Kanungu Districts in southwestern Uganda, located between 29.60° and 30.30° East and 0.35° and 1.50° South. The study sites are situated in the highland areas of Uganda, around 1800-1900 masl. We will refer to the study areas as the eastern and southwestern highlands. Annual rainfall in the east averages 1600 mm and in the southwest 1100-1200 mm, falling in two rainy seasons: a long season from March to July (season A) and a shorter season from September to December (season B). Main crops in the eastern highlands are coffee, banana and maize (intercropped with bush bean), and in the southwestern highlands beans (climbing and bush beans), banana, maize, Irish and sweet potato. The eastern highlands have better access to markets, a larger population density, a shorter history of climbing bean cultivation and poorer access to staking materials than the southwestern highlands (see Ronner et al. (2017) for more detail). Together, these differences represented the geographical context for the development of relevant options.

2.2 Co-design process and data collection

The co-design process consisted of three iterative cycles, roughly following different phases of the DEED cycle: demonstration (Explain & Explore), evaluation (Explore), and re-design (Design) of practices. The process was preceded by a characterization (Describe & Explain) of the two study areas focusing on farming systems, climbing bean cultivation and socio-economic characteristics of households. The characterization helped to develop an initial set of practices for the demonstrations.

2.2.1 Characterization

The study started in the eastern highlands during the first rainy season of 2014 (season 2014A) with a characterization of the area through transect walks and informal interviews (*n*=21) with key stakeholders including farmers, extension officers, representatives of farmers' organizations and NGO staff. The interviews aimed to establish the current role of climbing beans in the farming system, the extent to which farmers already cultivated them, and the most important production constraints. Farmers in two sub-counties of the eastern highlands (where farmers were least familiar with climbing beans) had already been introduced to on-farm try-outs of climbing beans with four treatments in 2013. Informal feedback on these try-outs was captured. The rapid characterization was followed by a baseline survey, which was also conducted in the southwestern highlands, with questions related to household characteristics, agricultural production and legume cultivation and marketing. A number of households from the baseline survey in both regions was selected for a detailed farm characterization, which contributed to the understanding of current cultivation of climbing beans and opportunities and constraints by different types of farmers

(Marinus, 2015). In the southwest, transect walks and informal interviews (*n*=12) were conducted after the baseline survey (at the start of season 2014B).

2.2.2 Demonstrations

Parallel to the characterization we started the first co-design cycle in the eastern highlands in season 2014A. Based on the rapid characterization and in consultation with key stakeholders the initial treatments for demonstrations were designed. Compared with 2013, the climbing bean dissemination approach changed from small try-outs on a limited number of farmers' fields to parish-level demonstrations on visible locations (road junctions, close to schools/ churches), in combination with larger numbers of farmers trying out technologies on their own field in so-called adaptation trials. Demonstrations in the southwestern highlands began in season 2014B. Demonstrations designed per region for season 2015A were repeated in season 2015B, to assess the performance of the same practices over two seasons. The number of demonstrations held in the eastern highlands was 7 in 2014A, 8 in 2014B, and 7 in both 2015A&B; in the southwest 5 in 2014B, 15 in 2015A and 10 in 2015B. Each demonstration had a maximum of 12 treatments, and compared varying combinations of varieties, inputs (manure, mineral fertilizer) and staking methods. A summary of the treatments per season and region is found in Annex A, Table A1. The adjustment of treatments after each co-design cycle is described as part of the results.

Demonstrations were planted on farmers' fields. Plot sizes in 2014A measured 10x10 m, but were decreased to 5x5 m in 2014B and 2015 as it was difficult to find large enough fields considering the small farm sizes in the densely populated highlands. Grain yields of the demonstrations were measured as unshelled, air-dry weights from sub-plots of 3x3 m in 2014A and whole plots from 2014B onwards. Only in 2014A a sub-sample of pods was shelled and oven-dried to establish dry grain weights. An average ratio of 0.7 between unshelled and shelled yields was found, which was applied to the rest of the data. Moisture content was highly variable, so all reported yields from the demonstrations represent air-dry, shelled grain yields.

2.2.3 Evaluations

Evaluations of the demonstrations were carried out in seasons 2014A, 2014B and 2015A. The evaluations served to identify which treatments farmers preferred, and to understand the reasons for preference. We aimed to distinguish preferences of farmers between the two geographical regions (eastern and southwestern highlands), and of farmers of different gender and socio-economic backgrounds. In 2014A, evaluations were carried out in four sub-counties in the eastern highlands, with six groups of farmers: men and women from low (LRE), medium (MRE) and high (HRE) resource endowed households. These six groups were identified in a participatory wealth ranking of households per sub-county, with people who were well-informed about the diversity of households in the community (e.g. teachers, community health workers, local government representatives, extension officers and farmers) (Bellon, 2001). Variables used to categorize households included farm size, number and type of livestock, type of housing, education (of children), type of employment and production orientation. For each group, five to eight people were identified for participation in the evaluations. The six groups evaluated the treatments separately, four times during the season (planting, staking, podding, harvest), by pairwise comparison and based on consensus. At each pairwise comparison, groups were also asked for their reasons for preference as an open question.

The evaluations in 2014A were logistically challenging and time-consuming. In search for a more easily applicable method for large-scale projects, demonstrations in season 2014B were evaluated only once during a field day (at podding of the beans). Evaluations were no longer done by the six groups, but by individual farmers visiting the field day. Scoring was used instead of pairwise comparison to facilitate statistical analysis. Farmers were also asked to fill in a reason for their score. Illiterate farmers were encouraged to ask help from staff or other farmers, but this method resulted in many missing or copied answers. To differentiate scores and reasons between different types of farmers, we also asked farmers to fill in gender, standard of living (better, same or worse as others in the village), and if they produced climbing beans mostly for home consumption or sale.

The evaluations in 2014B were easier, but information on farm types to disaggregate (reasons for) preference of treatments was less useful compared with 2014A. In 2015A we therefore evaluated the demonstrations with a random selection of farmers who participated in an adaptation trial, in which they tried one of the demonstrated technologies on their own field, and from whom household characteristics were recorded (Ronner et al., 2017). Farmers visited the demonstration trial during the season, but evaluated the treatments only once, after the season. Evaluation sessions were organized per sub-county. In each session, yields obtained in the demonstrations and estimates of input and labour costs calculated by researchers were presented. Farmers individually scored the performance of the treatments on a range of criteria (yield, variety traits, costs, labour, availability, etc.). These criteria were based on frequently mentioned reasons during evaluations in previous seasons. To cross-check the relevance of these criteria and their relative importance, farmers were also asked to judge the criteria as “important”, “somewhat important” or “not important” (Bellon, 2001).

2.2.4 Re-design

At the end of seasons 2014A and 2014B, the evaluations formed the basis for re-design sessions per sub-county, in which farmers, researchers, extension officers and NGO staff re-designed treatments for demonstrations in 2014B and 2015A respectively. Participating farmers were selected by researchers and extension staff for their experience with climbing bean cultivation, innovativeness and involvement in the community. The re-design sessions were facilitated by researchers. At the end of season 2014A we used a goal-oriented approach with back-casting (De Graaf et al., 2009; Robinson et al., 2011), to explore opportunities to improve climbing bean yields for different types of farmers. Participants estimated current ‘best’ yields (in bags per acre) achievable by HRE, MRE and LRE households as a starting point. We then explored opportunities to improve these yields. Back-casting was used to identify the steps needed to reach the improved yields. Researchers translated the outcomes of the re-design sessions into treatments for the demonstrations, and ensured that treatments were sufficiently replicated across sub-counties.

The re-design sessions in 2014B were informed by the results of the detailed characterization research performed in the season before, and by the evaluation of treatments during the field day. Hence, more information on opportunities and constraints for climbing bean cultivation was available. The session was therefore narrowed down to discuss the field day evaluation and reported challenges, followed by a direct focus on the development and improvement of practices for different types of farmers for season 2015A. No re-design session was held for season 2015B, as the aim was to assess performance of the same practices over two seasons.

2.3 Data analysis

Statistical analyses were performed in RStudio Version 1.0.143 (R Core Team, 2017). Differences in yield between the treatments in the demonstrations were analysed per season and region with a linear mixed model with treatment (variety, input, staking method) as fixed and farm as random factor. In season 2015B, two plot yields of > 6000 kg ha^{-1} were considered unrealistically large and were removed.

Evaluation methods, and therefore data analysis, differed between seasons. In 2014A, a matrix with each pairwise comparison of treatments per group and growth stage was constructed. Per comparison, a score of 1 was assigned to the treatment that was preferred, and a score of -1 to the treatment that was not preferred. When the group could not reach consensus (1% of comparisons), a 0 score was given. The average of these scores over all groups and growth stages resulted in an overall ranking of treatments. Differences in preference for treatments between gender and wealth groups were assessed through an analysis of deviance from the overall ranking (Coe, 2002). Each pairwise comparison received a binary value: 1 if the preferred treatment in the comparison complied with the overall ranking of treatments, and 0 if the preference did not comply. Differences in compliance with the overall ranking were assessed with a binomial generalized linear mixed model, with gender and wealth as fixed and group ID as random factor. Reasons for preference of treatments, asked as open question per group, were categorized. Per treatment, the number of times a certain category was mentioned was counted and divided over the total number of reasons given for that treatment.

In 2014B, original individual evaluation scores between 1 (very good) and 5 (very poor) were converted to a score between 1 and -1. Differences in scores between treatments and regions were assessed with a linear model. Because of an interaction between treatment and region influencing the scores, differences in scores between groups of different gender, standard of living and production orientation were analysed with linear models per region. Reasons for preference of treatments were considered unreliable because of the many missing and copied answers and were not analysed.

In 2015A, farmers' scoring of the performance of the treatments on each criteria was combined with the perceived importance of this criterion to obtain an 'attainment index' for each treatment, ranging from 1 to -1 and indicating how well a treatment met all the criteria valued by farmers (Bellon, 2001). A detailed description of the development of this attainment index is given in Annex A, A2. Differences in scores between regions, treatments and groups with different household characteristics were analysed with a linear mixed model, with group ID as random factor. Household characteristics included were: gender (0 = female, 1 = male) education of the farmer (0 = none or primary, 1 = secondary or higher), age of the household head, farm size (ha), number of livestock, months of food security (0 = < 10 months, 1 = 10-12 months), production orientation (0 = all or most farm produce consumed, 1 = half or most farm produce sold), off-farm income (0 = all income from farming, 1 = some to most income from off-farm activities), frequency of hiring labour (0 = never or sometimes, 1 = regularly or permanently) and income from salary, pension or remittances (0 = no, 1 = yes). For this analysis, an outlier in farm size of > 20 ha in the southwestern highlands was removed. Differences in importance of criteria (1 = very; 0 = somewhat; -1 = not important) were analysed with ordinal logistic regression. A cumulative link model (clm) in the package *Ordinal* was fitted with the default 'logit' link function.

3. Results

3.1 Characterization of the study areas and design of first options

At the start of the study, about 10% of farmers in the eastern highlands cultivated climbing beans, in the southwestern highlands about 50%. From the farmers who grew climbing beans, 75% intercropped climbing bean with banana and/or coffee in the eastern highlands. In the southwestern highlands sole cropping was more popular. In both regions, the use of inputs in climbing beans was low: in the eastern highlands, 25% (2 out of 8 farmers) grew climbing beans with DAP fertilizer and none of them used organic fertilizer. In the southwestern highlands none of the farmers cultivating climbing bean used mineral fertilizer, but 34% used organic fertilizer. Women or both men and women managed and took decisions about sale of climbing beans, with men playing a slightly larger role in the southwestern than eastern highlands. In both regions, women had a relatively larger role in management of the beans, and men in decisions about sale. Perceived constraints for climbing bean cultivation were staking and the additional labour demand in the east, and rats, birds and poor soil fertility in the southwest (Marinus, 2015).

Demonstrations started in the eastern highlands only, in season 2014A. The staking challenge in the east was taken as the basis for the design of the first demonstrations in this area. An improved climbing bean variety (NABE 26C) was planted with manure and TSP fertilizer and different staking methods: 1) the commonly used single wooden stakes; 2) a low-cost alternative in the form of ropes of banana fibre and sisal strings tied to a wooden frame and 3) tripods (three wooden stakes tied together). The latter were expected to enhance yields, as they would prevent the stakes from falling over under the weight of the beans. Although tripods increase labour at staking, they could reduce labour need during the season. The demonstrations were held in the two sub-counties where farmers were introduced to on-farm try-outs of climbing bean in 2013, and in two new sub-counties where climbing beans were more widely grown. The on-farm try-outs had already included different varieties and inputs (cattle manure, rhizobium inoculants and TSP fertilizer), so demonstrations in the first two sub-counties now focussed on the different staking methods. In the two new sub-counties – where farmers largely grew climbing beans without inputs – two varieties of climbing bean (the improved variety NABE 26C and a ‘local’ variety from Kabale district in the southwestern highlands) were demonstrated with and without manure and TSP fertilizer. As farmers also mentioned staking as a challenge in these sub-counties, the demonstrations also included the different staking methods.

3.2 Co-design process

3.2.1 First cycle (season 2014A-2014B)

Demonstration and evaluation

Grain yields in the demonstrations did not differ between varieties, but the application of manure + TSP significantly increased yield compared with the treatment without inputs (Fig. 3.1A). There was no interaction between varieties and inputs. Farmers preferred the treatments with inputs over the treatment without inputs, and this preference was more pronounced for variety NABE 26C although the difference in yield was smaller than for variety Kabale local. In the demonstration of staking methods, yields of banana fibre were significantly smaller than for single stakes (Fig. 3.1B). Partly, this could be related to stake length: banana fibre and sisal strings were shorter (137 cm) than single stakes and tripods (215 cm). Tripods did not yield better than single stakes, but farmers ranked tripods first.

Re-design

In the re-design sessions (*n*=4), stakeholders considered single stakes, sisal strings and tripods all as appropriate staking methods for good yields. Banana fibre was thought to break easily, but it was considered an option for poorer farmers. Banana fibre could be made stronger by braiding, but this was perceived to be laborious. Stakeholders would recommend TSP or DAP fertilizer (cheaper and easier to access than TSP at the time of study) to those who could afford it to obtain large yields; manure was suggested for medium and poorer farmers.

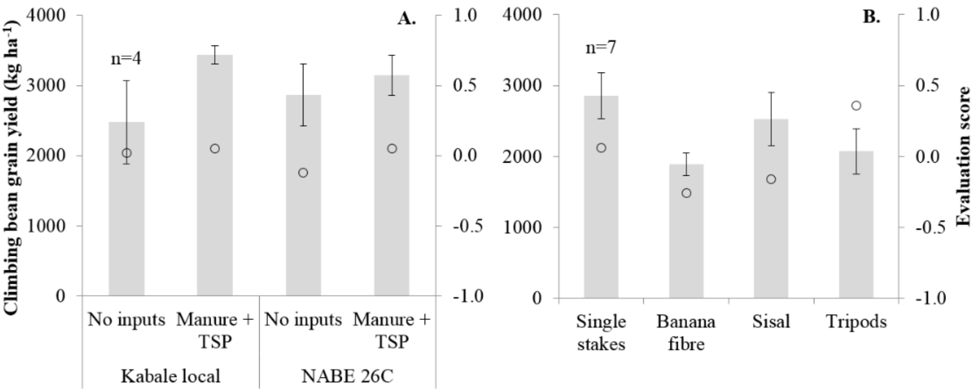


Fig. 3.1A&B: Climbing bean grain yields (bars, primary y-axis) and evaluation scores (circles, secondary y-axis) for varieties and inputs (A) and staking methods (variety NABE 26C with manure + TSP) (B) in demonstrations in the eastern highlands of Uganda, season 2014A. Error bars represent standard error of the mean, n = number of demonstrations per site.

Other than that, it proved difficult to develop suitable or innovative options for poorer farmers. Rather, stakeholders would advise poorer farmers to do everything the same as farmers with the largest yields, but on a small piece of land to reduce costs.

The evaluations and re-design sessions determined the design of the demonstrations in season 2014B (Table 3.1) An important change was the wooden frame for the banana fibre ropes and sisal strings. Farmers found the poles and rafters needed for this frame too expensive. Based on a suggestion from a farmer participating in re-design sessions (who had tested this option himself), the number of poles and rafters was reduced by half and two rows of strings instead of one were hung down from one rafter. Stakeholders also jointly decided to change the number of seeds per hole in the demonstrations from one to two. Farmers preferred to plant three to four (or more) seeds per hole because of experiences with poor germination on poor soils. Researchers suggested that seed that did not germinate would have to be replanted (‘gap filling’), but farmers found this too laborious. Farmers agreed, however, that planting many seeds per hole resulted in a loss of seed and overloading of stakes. Two seeds per hole was considered a good compromise between reducing the risk of poor germination and avoiding additional labour for gap filling.

Demonstrations in the southwestern highlands, starting in 2014B, had the same design as the re-designed trials in the east to identify regional differences and preferences. Only in one district in the southwest, papyrus was included as treatment as alternative for sisal or banana fibre, as papyrus was widely available in this district.

Table 3.1: Actions, reasons and information sources for re-design of the demonstrations in seasons 2014B and 2015A in the eastern and southwestern highlands of Uganda. Region-specific actions are specified with EH (eastern highlands) or SWH (southwestern highlands)

Re-design action	Reason	Source
Demonstrations 2014B		
Banana fibre ropes no longer demonstrated, only sisal strings	Poor results of banana fibre. Farmers could adapt the method to banana fibre	All stake-holders
Wooden frame for banana fibre ropes and sisal strings adjusted	Cost reduction	Farmer
Variety NABE 26C replaced by NABE 12C	Available in larger quantities	Researchers
Variety Kabale local and NABE 12C both demonstrated	Preference for varieties differed between groups	All stake-holders
Variety Kabale local no longer demonstrated on strings	Variety was considered too heavy and leafy for strings. Tripods were considered particularly suitable for this variety	All stake-holders
Number of seeds per hole increased from one to two	Compromise between farmers' practice of large number of seeds per hole (reducing risk of poor germination) and researchers' practice of one seed per hole and 'gap filling' of seed that did not germinate	All stake-holders
Demonstrations 2015A		
Comparison of TSP with DAP and DAP+NPK (EH)	Comparison of new fertilizer TSP with commonly used DAP and DAP + NPK	Farmers
Strings still demonstrated despite small evaluation score (EH)	Frame and strings considered expensive, but still wanted to evaluate performance	All stake-holders
Tripods no longer demonstrated (SWH)	Beans did not receive enough sunlight and aeration, affected by blight	Farmers
Comparison of row planting and broadcasting (SWH)	Row planting was expected to reduce damage of rats	NGO staff, extension
Removing growing tip of beans at 1.80m (SWH)	Avoid shade, enhance podding	Farmers
Comparison of local variety with (multiple) improved varieties (both regions)	Farmers preferred improved varieties for seed size, taste and maturity time but wanted comparison with local varieties	All stake-holders

3.2.2 Second cycle (season 2014B – 2015A)

Demonstration and evaluation

Yields of the demonstrations in the southwestern highlands were much larger than in the eastern highlands (Fig. 3.2). For varieties, yields of Kabale local were significantly larger than for NABE 12C in the southwest (Fig. 3.2A). In both regions, however, farmers evaluated NABE 12C significantly better. The use of inputs did not affect yields (Fig. 3.2B). This may explain why farmers in the southwest gave the largest score to the treatment without inputs (although in the east, this treatment received the smallest score). Differences in yield between the staking methods were not significant, but farmers in both regions gave the largest score to the treatment with the largest yield: in the east to tripods, in the southwest to sisal strings (Fig. 3.2C).

Re-design

The re-design sessions at the end of season 2014B in the eastern (n=3) and southwestern highlands (n=5) revealed differences between the two regions. In the east, the use of mineral fertilizer was much more common than in the southwest. Stakeholders in the east therefore had questions about the difference between the use of TSP and DAP fertilizer, and also mentioned that if they applied fertilizer to climbing bean themselves, they often applied DAP + NPK together. They wished to compare TSP, DAP and DAP+NPK. In the southwest, mineral fertilizer was rarely used and only applied to cash crops like Irish potato. Researchers suggested that with a rotation of Irish potatoes followed by climbing bean, the beans could benefit from the fertilizer applied to the potatoes and use the residual phosphorus. Stakeholders fed back that climbing beans grown after Irish potato do not do well (which could point at a problem of nematodes), so they commonly only grow climbing bean in rotation with sorghum or maize. The option of including the rotation with Irish potato over two seasons in the demonstrations was therefore not implemented.

Mineral fertilizer was still considered worth demonstrating as farmers would prefer this over scarce and bulky manure when available. Other particular issues highlighted in the southwest were problems with rats and birds. NGO and extension staff recognized this as a widespread problem and shared good practices such as clearing buffer zones around the field and planting in rows instead of broadcasting – the open spaces would scare the rats. To reduce bird damage, farmers were advised to plant all at the same time. Farmers in the southwest also mentioned that they were advised earlier on to cut the growing tip of the beans once they exceeded 1.80m, which would avoid shade from the canopy and enhance podding. A comparison with non-cut growth was suggested.

In both areas, farmers were particularly interested in the comparison of varieties. They mentioned that advantages of the demonstrated varieties over their local varieties were for instance seed size, taste and maturity time.

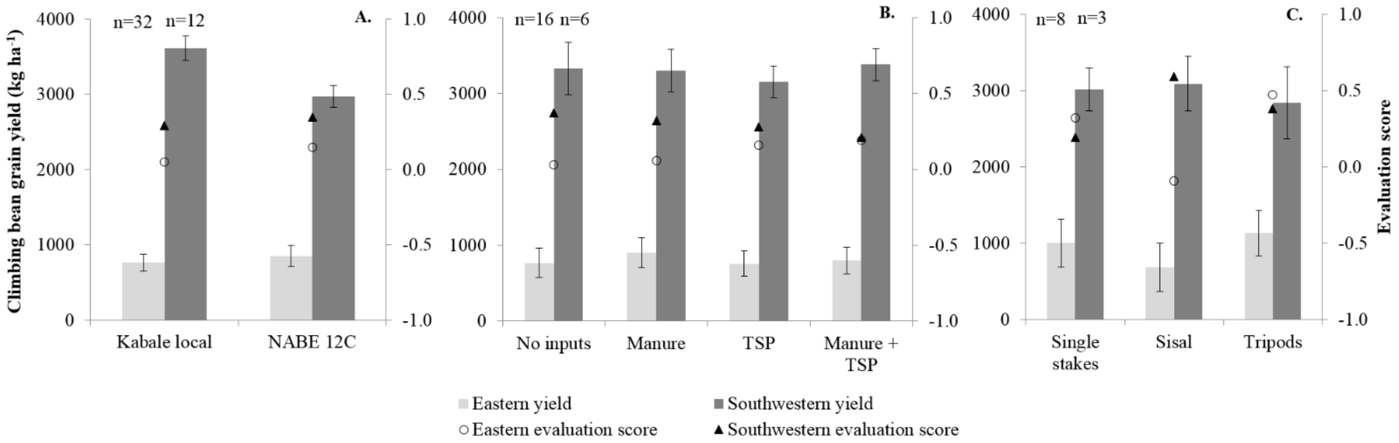


Fig. 3.2A, B & C: Climbing bean grain yields (primary y-axis) and evaluation scores (secondary y-axis) for varieties (average of all input treatments) (A), inputs (average of all varieties) (B) and staking methods (variety NABE 12C with manure + TSP) (C) in demonstrations in the eastern and southwestern highlands of Uganda, season 2014B. Error bars represent standard error of the mean, n = number of demonstrations per

It was suggested to include local varieties in the demonstration, to compare their performance with the improved varieties. The re-design sessions therefore led to a number of ‘research questions’, which were tried to be answered through the comparison of treatments in the demonstrations (Table 3.1).

3.2.3 Third cycle (2015A and 2015B)

Demonstration and evaluation

Yields in the southwestern highlands were again larger than in the eastern highlands in 2015A, but differences were smaller than in 2014B (Fig. 3.3). Varieties NABE 12C and Fe-enriched had larger yields than NABE 26C (Fig. 3.3A), but the difference was only significant in the southwest. Evaluation scores for NABE 26C were also significantly smaller than for the other varieties. Farmers in the eastern highlands gave the largest score to their ‘local’ variety NABE 10C. The use of inputs had a significant effect on yield only in the southwest: manure + TSP had a larger yield than the treatment without inputs (Fig. 3.3B). Conversely, evaluation scores for inputs did not differ in the southwest, but in the east manure + TSP received a significantly larger score than the treatment without inputs. The differences in yield between the staking methods were not significant. Farmers in both areas gave the largest score to single stakes (Fig. 3.3C). The comparison between TSP, DAP and DAP+NPK in the eastern highlands did not result in differences in yield (data not presented). In the southwest, row planting resulted in significantly larger yields than broadcasting; removing the growing tip of the climbing beans significantly reduced yields by more than 1 t ha^{-1}.

The treatments in the demonstrations roughly stayed the same in season 2015B. Only variety NABE 26C, heavily affected by bean anthracnose in preceding seasons, was left out of the demonstrations. Some trends in yields in 2015B differed from 2015A: in the east, yields were significantly larger for variety NABE 12C than NABE 10C and for TSP and manure + TSP than for the treatment without inputs. In the southwest, differences between inputs were not significant. Broadcasting and removal of the growing tip of the beans had larger yields than row planting and unlimited growth, but differences were not significant.

Re-design

There was no re-design session after season 2015B. After multiple seasons of co-design and farmers’ testing of climbing beans in adaptation trials we noticed, however, that 50-75% of the farmers in the eastern and some districts of the southwestern highlands continued intercropping of climbing beans with banana and/or coffee. All of the demonstrations showed sole crops of climbing beans, and little was known about the effects and best management practices for climbing beans in intercropping. We therefore set up a trial in seasons 2016A and 2016B to assess the effects of banana leaf pruning on light availability and climbing bean yields in intercropping, building on earlier work of Ntamwira (2013). A local and an improved climbing bean variety were exposed to pruning of banana up to eight leaves.

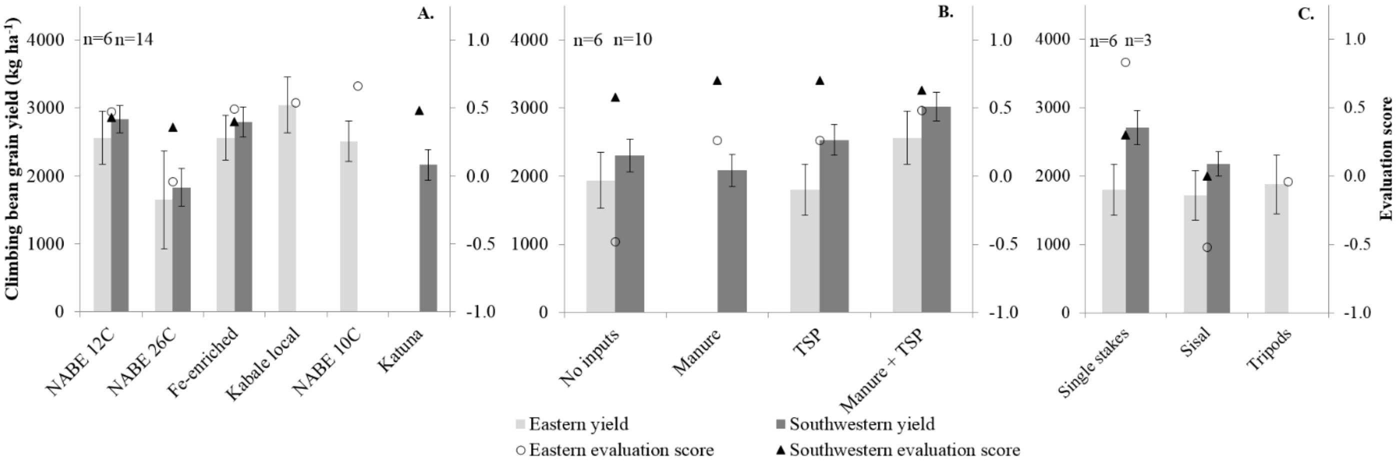


Fig. 3.3A, B & C: Climbing bean grain yields (primary y-axis) and evaluation scores (secondary y-axis) for varieties (with manure + TSP) (A), inputs (variety NABE 12C) (B) and staking methods (variety NABE 12C with TSP) (C) in demonstrations in the eastern and southwestern highlands of Uganda, season 2015A. Error bars represent standard error of the mean, n = number of demonstrations per site.

We expected enhanced light availability, resulting in larger climbing bean yields under pruning, and also expected differences between the two varieties as they may differ in their tolerance to shading. Pruning of banana significantly enhanced the fraction of PAR transmitted through the banana canopy, but did not show a significant effect on climbing bean yields. There was no difference in yield between the two varieties (data not presented).

3.3 Options for different types of farmers?

3.3.1 Preference of treatments

Evaluation scores were disaggregated by gender and wealth groups, to identify relevant options for different types of farmers (data not presented). Varieties were generally evaluated similarly. Only in season 2014B, women farmers in the eastern highlands gave variety Kabale local a significantly larger score than men. They specifically liked the taste and indicated to use the leaves as vegetable. Inputs were generally valued by wealthier farmers: manure + TSP received significantly larger scores from HRE farmers 2014A, from farmers producing climbing beans mostly for sale in 2014B and from farmers with relatively large farms in 2015A. The treatment without inputs received significantly larger scores from LRE farmers in 2014A and from farmers producing climbing beans mostly for home consumption in 2014B. Although strings were introduced as low-cost alternative for poorer farmers, they received significantly larger evaluation scores by farmers mostly producing for sale in the east in 2014B, and by farmers with larger farms and hiring labour more often in the southwest in 2015A. However, farmers producing mostly for sale in the southwest preferred single stakes in 2015A.

3.3.2 Reasons for preference

Reasons for preference may also differ between wealth and gender groups, which could explain their choices for a certain treatment. In 2014A, yield was the most frequently cited reason for preference of varieties (Fig. 3.4A). Other reasons were characteristics of the leaves (e.g. number, size, shape) and the plant in general (strong, healthy, tall). Reasons for preference hardly differed between groups; only yield seemed to be relatively more important to men than women. For inputs, yield was the most important reason for HRE farmers whereas LRE farmers mentioned costs more frequently (Fig. 3.4B). Men and women largely considered the same reasons. For staking methods, all groups of farmers mentioned strength of the method (tripods) or durability of the material (sisal strings vs banana fibre) more often than yield (Fig. 3.4C). LRE farmers also mentioned costs more frequently than yield, and labour demand of the staking methods more frequently than MRE and LRE farmers. Men and women gave similar reasons.

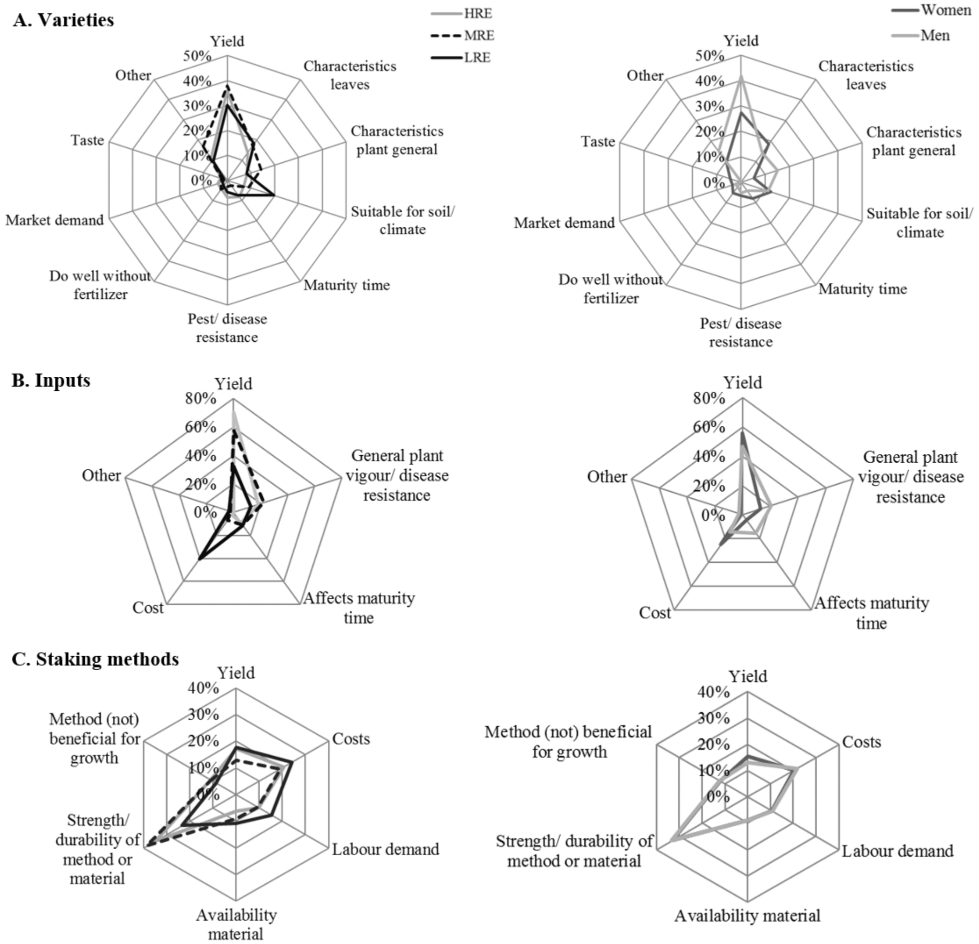


Fig. 3.4A, B & C: Reasons for preference of varieties (A), inputs (B) and staking methods (C) mentioned by farmers of low (LRE), medium (MRE) or high (HRE) resource endowment (left side) and men and women (right side) in pairwise comparison of treatments in the eastern highlands of Uganda, 2014A.

In 2015A, farmers again rated yield as important criterion for evaluation, although for varieties, inputs and staking methods other criteria received larger scores such as marketability, disease resistance, availability of inputs ease of the staking method and re-usability of staking material (Annex A, Table A3). The importance of criteria differed between regions: farmers in the eastern highlands found labour, the yield without fertilizer and the availability of inputs significantly more important; farmers in the southwest costs and marketability. Gender had no effect on the rating of importance. Relationships with household characteristics were variable. Farmers producing mostly for home consumption found costs and the benefit/ cost ratio more important than farmers producing mostly for sale. Other relationships seemed contradictory (farmers with off-farm income minded less about costs, but found the yield without fertilizer more important; farmers with an income from salary, pension or remittances in the east found the yield of varieties without fertilizer less important, but their counterparts in the southwest attached less value to the yield with fertilizer); counterintuitive (farmers with smaller farms found the yield with fertilizer more important; farmers producing mostly for sale found the maturity time of varieties more important); or could not be explained well (farmers from households with older household heads found the yield with fertilizer and the strength of staking material less important; farmers with larger farms found disease resistance more important). Differences in reasons for preference therefore remained largely unexplained based on individual household characteristics in 2015A.

3.3.3 Preference for co-designed versus researcher-designed options

Varieties NABE 10C and Katuna were introduced in the demonstrations of season 2015A at farmers' requests. These varieties received the largest evaluation scores in season 2015A, whereas yields of these varieties were not larger (in the southwest even smaller) than the newly introduced varieties (Fig. 3.3). Again, this demonstrates the importance of criteria other than yield. For instance, farmers gave variety NABE 10C the largest score for grain colour, maturity time and suitability for the climate, whereas NABE 12C was particularly valued for yield (with fertilizer) and grain size, but scored negatively for disease resistance. The same holds for variety Katuna in the southwest: the scores for insect tolerance and disease resistance were better for Katuna than NABE 12C, even though they had the same score for yield.

For inputs, the co-design process resulted in the inclusion of DAP and DAP+NPK in the demonstrations in the eastern highlands in season 2015A, next to TSP as the researcher best-bet option. Farmers gave the largest evaluation score to the treatment with DAP. In contrast, DAP+NPK received a negative score; only slightly better than the control. Both DAP and DAP+NPK got much better scores for the availability of inputs than TSP and manure. Currently, these inputs are also cheaper than TSP in the area. Farmers in the southwest gave manure or TSP only larger scores than manure + TSP.

Among the staking methods, strings were included as low-cost alternative for poorer farmers. Strings consistently received the lowest scores, however, except in the southwest in 2014B. In both 2014A and 2015A, the availability of the material and the additional labour demand were seen as negative aspects of strings versus single stakes. In 2015A, the costs, ease of the method and re-usability of the material all received a negative score for strings. Single stakes, the researcher best-bet, received the largest score for yield and ease of the method. Tripods were particularly valued for the strength of the method, but received a smaller score than single stakes for all other criteria.

3.4 Basket of options and out-scaling tool

Through the iterative co-design process, the initial researcher designed practices were modified, and new practices were added. This process led to the development of a basket of options (Table 3.2). Every season, options from this basket were added, refined or discarded. Such a basket of options could be used by other projects or development agents aiming to expand climbing bean cultivation to new areas.

Table 3.2: Researcher best-bet practices; additional options tested during the co-design process and reasons for preference (other than yield) of the additional options in the eastern and southwestern highlands of Uganda, seasons 2014A-2015B. Researcher and additional options resulting from the co-design process together form a basket of options for climbing bean cultivation.

	Researcher best-bet	Additional options	Reasons for preference
Varieties	Improved variety	Multiple varieties	Multiple variety traits
Inputs	Manure + TSP	No inputs	Costs
		Manure or TSP only	Availability, costs
		DAP	Availability, costs
Staking	Single stakes	Strings	Availability, costs
		Tripods	Strength, labour
	Wooden stakes	Banana fibre	Availability, costs
		Papyrus	Availability, costs
		Maize stalks	Availability, costs
		Sisal	Strength, re-usability, costs
		Nylon	Strength, re-usability, costs
	Stakes > 1.75m	Shorter stakes	Availability, control bird damage
Other practices	Sole cropping	Intercropping	Land scarcity, risk reduction
	Row planting	Broadcasting/ random planting	Labour
	One seed per hole	Two or more seeds per hole	Risk reduction, labour

The identification of reasons for preference for certain options provided insight in the context in which farmers make choices. Certain options were preferred because of farmers' production objectives, their production constraints, or in the context of a certain agro-ecological environment or farming system. Hence, an 'option by context' matrix could serve as a guide for out-scaling and extension (Fig. 3.5). With a new project, or expansion to new areas, a rapid characterization of the distinguishing context factors is a first step. Options suitable for the context at hand can then be selected from the matrix. Such a matrix should not be seen as prescriptive, but provides guidance in the alternatives available to different types of farmers. Farmers' feedback on the experimentation with the options can also be used to refine the matrix.

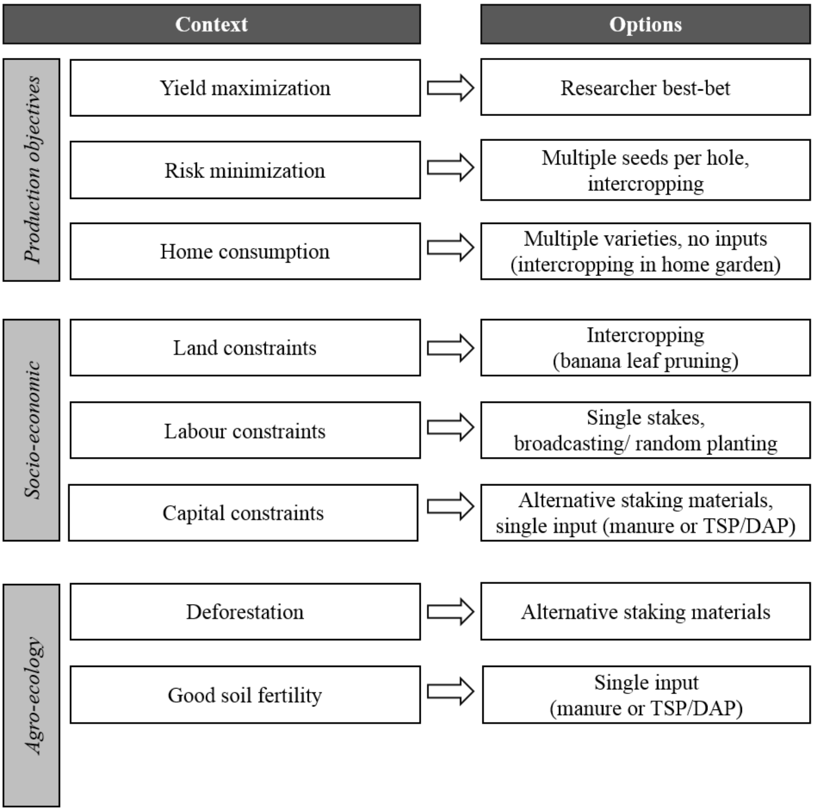


Fig. 3.5: 'Option-by-context' matrix as out-scaling tool for climbing bean cultivation, showing how researcher best-bet and additional options fit into certain contexts.

4. Discussion

4.1 Lessons learned from developing and applying a co-design process

We developed and applied a co-design process in the context of a large-scale dissemination project which aimed to disseminate technologies through demonstrations (and farmers trying out technologies on their own field). The re-design of the technologies in the demonstrations each season allowed taking into account treatments that farmers valued, but at the same time this meant that treatments could not always be compared over multiple seasons. This presented a trade-off between reflexive design on the one hand (Mierlo et al., 2010; Falconnier et al., 2017), and agronomic research requirements on the other. However, even those treatments that could be compared over multiple seasons showed a large variation in yield (in line with earlier findings on farmers' fields of Franke et al., 2016; Ronner et al., 2017). After four seasons, we only identified a significant effect on yield of manure + TSP compared with the treatment without inputs. This made it hard to draw firm conclusions and recommendations for the basket of options based on yield data only.

Different evaluation methods were used to capture (reasons for) preference of treatments by different types of farmers. The different methods revealed a trade-off between the degree of detail and the ease of the method. We considered the method used in 2015A (scoring instead of ranking and individual instead of group evaluations) useful, as it allowed statistical analyses. The scoring of the importance of criteria for the separate practices (varieties, inputs, management practices, staking) provided guidance for the re-design process. However, we also noted that farmers judged most criteria as (very) important (Annex A, Table A3), which limited a distinction between criteria. Ranking of criteria could have provided additional value in this case. The evaluations in 2015A took place after the season instead of during the season (in 2014A&B), so that actual grain yields could be presented to the farmers instead of visual judgements of treatments in the fields. This was considered an advantage, as farmers in 2014A&B often commented "we will see after harvest" – reflecting yield as an evaluation criterion. Moreover, average regional yields were presented, which gave farmers an impression of the overall performance beyond what they had seen in their own demonstration.

The re-design sessions proved to be useful in receiving general feedback from farmers on the performance of the demonstrations, and hearing about region-specific challenges. The sessions also facilitated knowledge exchange between the different stakeholders and led to modifications of practices in the demonstration (staking methods, number of seeds per hole, additional treatments) that better reflected farmers' possibilities and preferences. Some issues raised during the re-design sessions did not fit within the scope of a legume project. The problems of rats, for instance, would require an integrated strategy with a whole new range of stakeholders. The co-design process did help to flag such issues, which could still lead to follow-up discussions with other rural development projects.

4.2 A relevant basket of options for different types of farmers?

The co-design process showed added value on three aspects. First, the process broadened the scope of the evaluation of technologies from 'yield' or solely researchers' criteria to a wider range of variables. Farmers, for instance, considered specific variety traits, marketability, availability of inputs and ease of the staking method to be more important than yield (cf. Kitch et al., 1998; Snapp et al., 2002b; Vandeplas et al., 2010). The larger evaluation scores for the treatments with manure or TSP only compared with the combination of manure + TSP in the southwest also showed the relevance of demonstrating single inputs, instead of just the researchers' best-bet combination of manure + TSP that actually only few farmers will be able to apply (cf. Aune and Bationo, 2008; Vanlauwe et al., 2010). Capturing these multiple perspectives helped to explain why farmers may not always prefer treatments that could give them the largest yield (Biggs, 1990; Douthwaite et al., 2001).

Second, the knowledge exchange between different stakeholders resulted in enhanced relevance of the demonstrated options, including the introduction of new options. Notable contributions from farmers were the suggestion for cost reduction of the banana fibre and sisal string staking method and for risk and labour reduction related to the number of seeds per hole. Farmers also provided immediate feedback on the suggestion from researchers to rotate climbing bean with Irish potato: in their view, this practice would not do well in the area. The removal of the growing tip of the bean was an example of a practice suggested by farmers, although the practice was discarded again due to the poor performance. Researchers brought in new varieties and TSP fertilizer, but also tried to address local issues with options that had been tried out in other countries such as the different staking methods or testing of management recommendations for climbing bean intercropping with banana. Extension officers and NGO partners mainly had a role in sharing of good practices or advice, e.g. on pest and disease management. Even when this did not lead to modifications in the demonstrations, their contributions helped to answer questions from farmers on local issues. The co-design process therefore added value over only demonstrating a researcher best-bet combination of practices expecting to lead to the largest yields, but also over just supplying a climbing bean variety and leaving experimentation and adaptation entirely up to farmers (cf. Biggs, 1990; Sumberg et al., 2003).

Third, the co-design process provided insights in the potential to develop technologies for different types of farmers. The geographical context often presented the clearest differences, e.g. in terms of preference for varieties, availability of inputs and staking materials, use of intercropping or local challenges such as birds and rats. The development of options for farmers with different socio-economic backgrounds proved more difficult. Following our hypothesis that the co-design process would lead to relevant options for different types of farmers given certain resource constraints, the introduction of banana fibre and sisal string was expected to provide a low-cost alternative staking option specifically for poorer farmers. The co-design process revealed, however, that farmers still found this staking method too expensive or labour intensive. Also, poorer farmers producing for home consumption found costs and labour more important aspects of technologies than wealthier farmers, and preferred the treatment without inputs. This shows the difficulty of finding a suitable alternative for resource poor farmers: they face multiple constraints in multiple production factors and have little room for manoeuvre (Tittonell et al., 2007; Franke et al., 2016). Only changes at the institutional level may really create opportunities for these farmers (Dogliotti et al., 2014; Schut et al., 2016). Although we could not explain all differences in preference based on geographical, socio-economic or gender characteristics, the co-design process improved the visibility of the diversity of users, and ensured that options for farmers with different preferences were included in the demonstrations. Some stakeholders involved in the re-design sessions made comments like: *"staking should not be a problem for serious farmers"*, *"strings are just a last resort option"*, *"farmers will find yield the most important"* or *"only some women will like variety Kabale local"*. These statements may reflect the preferences of wealthier, male farmers who often have a more visible presence in interactions with researchers (Cornwall, 2003; Pircher et al., 2013), but they neglect other perspectives. The disaggregated analysis of the evaluation of practices allowed the identification of a wider range of options for farmers with different preferences, such as the inclusion of multiple varieties, single input options (manure or TSP only) or management recommendation for farmers growing climbing beans in intercropping with banana.

4.3 Applicability of a co-design process in large-scale projects

The co-design process resulted in the development of a basket of options for climbing bean cultivation for farmers in different contexts that is applicable across the East African highlands. New initiatives could take these options as a starting point, select the most promising options through the option-by-context matrix and add to or refine the basket of options (Coe et al., 2014). The characterization of a new area through a combination of a Rapid Rural Appraisal, household survey and maps of forest cover or soil fertility could help to describe the relevant context.

We aimed to search for methods that could include the perspectives of users of a technology in large-scale projects. Although some methods applied in this study were time consuming, the basic principles of demonstrations, evaluations and re-design could be applied at a larger scale. Local teams implementing activities in the field can carry out evaluations with a representative sub-sample of farmers. For varieties and inputs, previous studies give a good indication of farmers' criteria and preferences (Vandeplas et al., 2010; Misiko, 2013; Kamanga et al., 2014). For new technologies or practices (such as the staking methods), it is still useful to identify farmers' criteria for evaluation of this particular technology (Bellon, 2001; Nelson and Coe, 2014). The collection of background (household) information from these farmers as part of their participation in the project would enable disaggregated analyses. These insights can be combined with analyses of yields, advice from extension/NGO staff, private sector partners, etc., to move beyond 'farmers evaluating and researchers deciding which options to continue with' (Pircher et al., 2013). An important step made during this study to ensure rapid data analysis and feedback loops was the conversion to tablet-based data collection instead of paper forms.

The diversity of preferences and inconsistent or unexplained relationships with household characteristics advocates for the development of a basket of options, consisting of practices that can be combined in a flexible manner; rather than fixed combinations of practices or 'packages' for every farm type (Sumberg et al., 2003). Guidelines on how to use practices in which contexts and suggestions on how to experiment with different practices can be made available for extension, e.g. through manuals and boundary tools such as the option-by-context matrix (Coe et al., 2014; Clark et al., 2016). Such an approach provides a practical alternative for detailed, site-specific recommendations that are only applicable to single communities on the one hand, and one-size-fits-all recommendations that are out of reach or not relevant for the majority of farmers on the other.

5. Conclusion

In this study we evaluated the usefulness of a co-design process to generate a relevant basket of options for a diversity of farmers. The study showed how farmers use multiple evaluation criteria, of which yield is but one. These multiple criteria are important to judge the performance and relevance of technologies in the design process; not only as factors explaining (non-)adoption afterwards. Although the co-design process did not lead to the design of entirely new technologies, the process proved to be useful in enriching the technology options through the generation and selection of relevant alternatives for the initial set of practices. This resulted in a basket of options. The adaptation of the string staking method and the research on management recommendations for intercropping are two examples of options that would have been overlooked without the interactions between multiple stakeholders. The process also revealed the diversity of preferences among users. Future projects could benefit from a 'light' version of the co-design process to include this diversity in the design and selection of technology options. The process as applied in this study was time-consuming, but the basket of options developed can be applied across the East-African highlands with the option-by-context matrix as a starting point for out-scaling. The study also showed, however, that consistent recommendations based on household characteristics were difficult to identify. This strengthens the plea for a basket of options with flexible combinations of practices rather than narrowly specified technology packages for static farm types. Finally, the co-design process showed the difficulty of developing options for poor farmers, as they are confronted with multiple, binding constraints. Technology development should therefore go hand in hand with institutional innovation to relieve constraints for these farmers.

Acknowledgements

We thank the Bill & Melinda Gates Foundation for partnering in this research through a grant to Wageningen University to support the project N2Africa: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (www.N2Africa.org). We also thank the farmers, field assistants, extension officers, dissemination partners (Africa 2000 Network, VECO), Wytze Marinus and Jan Hüskens (Wageningen University), John Ssekamwa, Justine Onyinge, Anthony Epel and Connetie Ayesiga Ninaz (N2Africa-Uganda) for their help with data collection.

Chapter 4

Farmers' use and adaptation of improved climbing bean production practices in the highlands of Uganda

This chapter is published as:
Ronner, E., Descheemaeker, K., Almekinders, C.J.M., Ebanyat, P., Giller, K.E., 2017, Farmers' use and adaptation of improved climbing bean production practices in the highlands of Uganda. Agriculture, Ecosystems and Environment.
http://dx.doi.org/10.1016/j.agee.2017.09.004

Abstract

Climbing beans offer potential for sustainable intensification of agriculture, but their cultivation constitutes a relatively complex technology consisting of multiple components or practices. We studied uptake of improved climbing bean production practices (improved variety, input use and management practices) through co-designed demonstrations and farmer-managed adaptation trials with 374 smallholder farmers in eastern and southwestern Uganda. A sub-set of these farmers was monitored one to three seasons after introduction. About 70% of the farmers re-planted climbing beans one season after the adaptation trial, with significant differences between eastern (50%) and southwestern Uganda (80-90%). Only 1% of the farmers used all of the improved practices and 99% adapted the technology. On average, farmers used half of the practices in different combinations, and all farmers used at least one of the practices. Yield variability of the trials was large and on average, trial plots did not yield more than farmers' own climbing bean plots. Yet, achieved yields did not influence whether farmers continued to cultivate climbing bean in the subsequent season. Uptake of climbing beans varied with household characteristics: poorer farmers cultivated climbing beans more often but used fewer of the best-bet practices; male farmers generally used more practices than female farmers. Planting by poorer farmers resulted in adaptations such growing climbing beans without fertilizer and with fewer and shorter stakes. Other relationships were often inconsistent and farmers changed practices from season to season. The diversity of farmer responses complicates the development of recommendation domains and warrants the development of a basket of options from which farmers can choose. Our study shows how adoption of technologies consisting of multiple components is a complicated process that is hard to capture through the measurement of an adoption rate at a single point in time.

Keywords: *Phaseolus vulgaris*, legumes, co-design, adoption, smallholder, nitrogen fixation, East Africa

1. Introduction

The East African highlands are densely populated, and decreasing farm sizes and declining soil fertility status require agricultural intensification to sustain food production and avoid encroachment into forests (Benin et al., 2002; Sassen et al., 2013; De Bauw et al., 2016). The integration of legumes in farming systems provides a pathway for sustainable intensification of agriculture (Giller and Cadisch, 1995; Snapp et al., 2002b). Common bean is an important staple crop in many East African countries and a source of protein, calories, minerals and vitamins. Climbing beans offer potential to intensify bean production compared with bush beans, with yield potential being their greatest advantage: up to 4 to 5 tons ha^{-1} (Checa et al., 2006) versus 1 to 2 tons ha^{-1} for bush beans in Uganda (Kaizzi et al., 2012). Climbing beans are also better resistant against fungal and root rot diseases (Mcharo and Katafiire, 2014), and have a better potential to fix nitrogen (Bliss, 1993; Wortmann, 2001; Ramaekers et al., 2013). Improved varieties of climbing bean were introduced in Rwanda in the 1980s (Sperling and Muyaneza, 1995) and were rapidly adopted, particularly in the highlands of northern Rwanda. Climbing beans spread from Rwanda to neighbouring countries such as Burundi, DRC and Uganda in areas above 1600 meters above sea level (masl) (Franke et al., 2016).

Climbing beans are not a simple replacement of bush beans as the latter are often intercropped with maize or grown as an understory in banana-coffee systems. Elsewhere, in Latin America, maize and climbing bean intercropping is common (Davis and Garcia, 1983; Clark and Francis, 1985), but in African systems where elevation is lower climbing beans grow too fast and smother the maize. Climbing beans are therefore better grown as sole crops. In addition, climbing beans need stakes to realize their climbing potential, implying additional costs for materials and labour. Moreover, because of their larger biomass production, climbing beans require more nutrient inputs (Sperling and Muyaneza, 1995). Altogether, adopting climbing beans constitutes a relatively complex change in farming practice and is not a mere replacement of cultivar.

Best yields of climbing bean are achieved through a combination of practices: the use of improved varieties, phosphate fertilizer and organic fertilizer, row planting, sole cropping, a high density of strong and tall stakes, timely planting and proper weeding (Kaizzi et al., 2012; Franke et al., 2016). Given the heterogeneity of African smallholder farming systems, these practices and their optimal combination (together representing the 'climbing bean technology') need to be tailored to fit the local agro-ecological, socio-economic and cultural environment (Giller et al., 2011; Descheemaeker et al., 2016b). As argued for other complex technologies consisting of multiple components, it is unlikely that all farmers would adopt all components, or that adoption takes place as a simple, linear process (Glover et al., 2016; Brown et al., 2017).

In this study, we used the outcome of a co-design process with farmers, extension officers, NGOs and researchers to introduce improved climbing bean production practices among smallholder farmers in the highlands of eastern and southwestern Uganda. Farmers applied these practices on their own field in a so-called 'adaptation trial' and were monitored during and after the trial. Feedback from farmers' experimentation and their adaptation of the technology, and understanding the reasons for (non-)use of practices in subsequent seasons provides insight in the adoption process and dynamics over time (Doss, 2006).

We also explored the relationship between the use of climbing bean production practices and a range of agro-ecological, plot and household characteristics. Variables selected were largely based on previous work on understanding the heterogeneity of African smallholder farming systems (Tittonell et al., 2005a; Tittonell et al., 2010; Giller et al., 2011), and on adoption studies of agricultural technologies (Feder and Umali, 1993; Knowler and Bradshaw, 2007; Kassie et al., 2015) and legumes (Farrow et al., 2016). Agro-ecological characteristics are important to determine the biophysical relevance of technologies (Farrow et al., 2016). Plot characteristics such as land tenure, soil fertility and soil depth are often considered in relationship with the willingness to invest in improvement of the land (Kerr et al., 2007; Banadda, 2010; Kassie et al., 2015). Household characteristics (demographics, access to capital and labour, production orientation and importance of farm/ off-farm income) define farmers' ability to implement new technologies (Feder and Umali, 1993; Marenya and Barrett, 2007; Pircher et al., 2013). We also considered farmers' previous experience with the technology, as decisions to use a certain practice may be related to earlier choices (Cowan and Gunby, 1996; Kassie et al., 2013).

Our objective was to understand the change in climbing bean production practices and the reasons for these changes among farmers of different geographical areas and socio-economic backgrounds, and to use this understanding to inform technology re-design and to delineate recommendation domains. We hypothesized that the majority of farmers would not adopt all components of the climbing bean technology, and that the use of practices would be related to performance of the adaptation trial, household wealth and farmers' previous experience with the practices.

2. Methodology

2.1 Study area

The study was conducted in Kapchorwa District in eastern Uganda, located between 34.30° and 34.55° East and 1.18° and 1.50° North, and Kabale and Kanungu Districts in southwestern Uganda, located between 29.60° and 30.30° East and 0.35° and 1.50° South. The study sites are situated in the highland areas of Uganda, around 1800-1900 masl (Table 4.1). Both have two rainy seasons per year, and average annual rainfall in Kapchorwa district is 400-500 mm more than in the other two districts. Other important differences between the districts include soil type (of volcanic origin in Kapchorwa district and parts of Kanungu district, and Acrisols in Kabale district), market access, population density and experience with climbing bean cultivation, although the latter also differs within districts.

Table 4.1: Characteristics of study sites in eastern and southwestern Uganda

	Southwestern Uganda		Eastern Uganda
District	Kabale	Kanungu	Kapchorwa
Elevation (masl)	1800	1850	1900
Rainfall (mm)[1]	1100	1200	1600
Cropping season A	Feb-Jun	Feb-Jun	Mar-Jul
Cropping season B	Aug-Nov	Aug-Nov	Sep-Dec
Soil type[2]	Acrisols	Acrisols/ Andosols	Nitisols
Distance to main market	Medium: 1.5 to 2 hours (dirt road)	Poor: 2.5 to 3 hours (dirt road)	Good: 1 to 1.5 hours (tarmac road)
Population density (people km^{-1})[3]	207	57	297
Experience climbing bean cultivation	Medium	Long	Short

[1] *climate-data.org;* [2] *www.soilgrids.org;* [3] *www.ubos.org.*

2.2 Dissemination of the climbing bean technology

The study was conducted in the context of the N2Africa project. The climbing bean technology (combination of improved variety, input use and management practices) was disseminated in the format of 'mother and baby trials' (Snapp, 2002), whereby a large demonstration plot facilitated learning and comparison of a range of treatments throughout the season, and small trials enabled the testing of one treatment on farmers' fields. In this study we call these 'demonstration' and 'adaptation' trials respectively.

Demonstration trials showed a number of varieties, inputs, staking methods and other agronomic management practices. Treatments for these demonstration trials were developed in a co-design process with farmers, researchers, extension officers and NGO staff over a total of four seasons in 2014 and 2015 (see Descheemaeker et al. (2016b)). The demonstrations started with a number of practices distilled from researchers' experiences. Farmers evaluated the practices, which served as input for a re-design session with all stakeholders in which practices were modified, added or discarded to develop a 'basket of options' (Giller et al., 2011). Treatments in the demonstration therefore varied over locations and seasons (Annex B, Table B1). However, every season it was ensured that a 'researcher best-bet' and a control treatment were included.

We defined the *researcher best-bet technology* as the combination of practices that is expected to give the best climbing bean yield, and was based on previous research on legumes in general and climbing beans specifically by Uganda's National Agricultural Research

Organisation (NARO) and project staff. The researcher best-bet technology consisted of the following components: an improved climbing bean variety with cattle manure and Triple Super Phosphate (TSP), planted as sole crop and in rows spaced at 50 cm between rows and 25 cm between plants, 2 seeds per hole (i.e. a density of 160,000 plants per ha), 40,000 stakes per ha and stakes taller than 1.75 m. The control treatment had the same variety and management practices but was planted without manure and TSP. The researcher best-bet and the control both had single, wooden stakes.

Because climbing beans were new for many farmers in Kapchorwa and poor availability of stakes due to deforestation was mentioned as important constraint for the cultivation of climbing beans, a low-cost and environmentally sustainable alternative in the form of strings from sisal, banana fibre or papyrus was offered in the demonstrations. Tripods (three wooden stakes tied together) were expected to enhance yields and were included in the demonstrations in Kapchorwa as well.

For the ***adaptation trials*** farmers received a package of seed of an improved climbing bean variety and Triple Super Phosphate (TSP) fertilizer at the equivalent of 15 kg P ha^{-1}. An instruction leaflet with directions for planting and a number of best management practices was handed out together with the package, but farmers planted the package without any further assistance. Adaptation trials were planted in seasons 2014B, 2015A and 2015B. In season 2014B, the leaflet instructed to plant two plots of 5 x 5 m: a plot with climbing bean variety NABE 26C with TSP, and a control plot with the same variety without TSP. Seeds for the two plots and TSP for one plot were provided in the package. Planting (spacing, density, sole or intercropping), staking (method, material) and weeding (timing, frequency) was left to the farmers (i.e. the leaflet specified that farmers could plant the way they normally do). In seasons 2015A and 2015B, farmers received inputs for one climbing bean plot only. Farmers could choose from a number of varieties, and about 80% received TSP fertilizer as well (based on availability). The idea of a control plot was abandoned in these seasons, as only few farmers had planted a comparable control plot previously. Instead, farmers were encouraged to compare the package with the way they normally grow climbing beans, and hence to plant the adaptation trial next to their own climbing bean variety with the practices they would normally apply. The plots could therefore differ with respect to multiple practices. In 2015, best practices for planting (plant spacing, number of seeds per hole) and staking were also included in the instruction leaflet. We will refer to the ‘N2Africa plot’ planted with the seed and fertilizer provided for the adaptation trial, the ‘control plot’ without TSP in 2014B and the ‘own climbing bean plot’ in 2015A&B.

2.3 Data collection

2.3.1 Monitoring of adaptation trials

In seasons 2014B, 2015A and 2015B a stratified, random sub-set of farmers who planted an adaptation trial was monitored. Stratification was based on the variety received, with a minimum of five farmers per variety per district. The campaign started in 2014B in Kapchorwa District, eastern Uganda. From 2015A onwards, Kabale and Kanungu Districts were included. Over the three seasons, a total of 374 farmers from which 235 in Kapchorwa, 71 in Kabale and 68 in Kanungu were monitored (Table 4.2). Monitoring took place through a survey, tablet-based and programmed in ODK software (https://opendatakit.org/). The survey was conducted among the farmers who implemented the trial. If this person was not around, the household was not surveyed and the next household on the list with the same variety was sampled. The survey consisted of two parts: the first part was conducted in the field, before harvest. This part contained questions related to planting of the package, implementation of management practices and reasons for (not) applying these practices. The survey also contained questions on the characteristics of the field in which the trial was planted, and a number of questions on household characteristics. Field measurements (size of the N2Africa and own plot, plant density, stake density and length, etc.) were also taken.

Table 4.2: Total number of farmers participating in adaptation trials, number of farmers monitored and harvest data available for farmers in Kapchorwa, Kabale and Kanungu districts in seasons 2014B, 2015A and 2015B

		2014B	2015A	2015B	Total
Kabale	Farmers participating	-	68	51	119
	Farmers monitored	-	41	30	71
	Farmers with harvest data	-	11	10	22
Kanungu	Farmers participating	-	100	106	206
	Farmers monitored	-	34	34	68
	Farmers with harvest data	-	20	21	38
Kapchorwa	Farmers participating	271	399	304	974
	Farmers monitored	88	88	59	235
	Farmers with harvest data	19	42	25	91

2.3.2 Measurements of climbing bean yield

For the second part of the survey after harvest, farmers with two clearly distinguishable plots suitable for harvest measurements (i.e. plots planted in the same or a nearby field, at more or less the same time (average difference was 4 days)) were selected. Questions were asked on the inputs applied, the timing of management practices and problems (pest, disease, drought, waterlogging, etc.) encountered during the season. Farmers evaluated the performance of the trial and their own climbing bean plot. The bean harvest of the two total plots was measured with a digital scale as shelled or unshelled, according to how the farmer harvested the beans. In some cases the own plot was too large to harvest in total and a smaller harvest area was measured, representative for the field and easy to delineate for the farmer. Unshelled yields were converted to shelled yields with a factor of 0.7 based on earlier trials (no difference between varieties). Farmers also recorded if they had already sold or consumed part of the harvest. This amount was added to the measured grain weight.

2.3.3 Use of practices in the season(s) after the adaptation trial

Another follow-up survey was carried out in the season after farmers participated in the adaptation trials. This survey aimed to assess the cultivation of climbing beans and the use of practices with farmers' own seeds and inputs one season after participation in the trial. The follow-up survey was conducted among a random sub-sample of the farmers who were monitored during the adaptation trials. Again, the farmer who was responsible for the implementation was surveyed. This survey was carried out in seasons 2015A and 2015B in Kapchorwa, and in 2015B in Kabale and Kanungu (Table 4.3A) among a total of 148 farmers. The survey contained questions related to the practices shown in the demonstration trial in the previous season, to what extent these practices were new for farmers, and if farmers currently cultivated climbing beans with their own seed and used any of the previously demonstrated practices. The survey also contained open questions related to the reasons for (non-)use of any of the practices.

Among the 29 farmers who participated in the follow-up survey in Kapchorwa in 2015A (Table 4.3A-B, arrow 1), a random subset of 20 farmers was monitored for a second season in 2015B (Table 4.3B, arrow 2). In addition, the survey was conducted in Kapchorwa in 2014A, among 43 farmers (Table 4.3B) who participated in earlier climbing bean trials in seasons 2013A and 2013B. A random sub-sample of these 43 farmers was also monitored for a second season (30 farmers, Table 4.3B, arrow 3), and again a sub-sample of these 30 farmers (those who could be traced back) for a third season (20 farmers, Table 4.3B, arrow 4). This made it possible to track the use of practices over time among the same group of farmers. These farmers, monitored for more than one season in Kapchorwa district only, were treated as a separate group within the study (Section 3.4).

2.4 Data analysis

2.4.1 Measuring use, non-use and adaptation

We used the framework for measurements of adoption of complex technologies by Brown et al. (2017) to define use, non-use and adaptation of the researcher best-bet technology.

Table 4.3A&B: Sub-set of farmers monitored one season after participation in adaptation trials in Kapchorwa, Kabale and Kanungu districts in seasons 2015A and 2015B (n = 148 unique farmers) (A), and sub-set of farmers monitored for multiple seasons in Kapchorwa district in seasons 2014A, 2015A and 2015B (B). Arrows indicate sub-sets of the same farmers that were monitored for one (arrow 1), two (arrows 2 and 3) or three seasons (arrow 4) after the adaptation trials.

A.	One season	
	2015A	2015B
Kabale		25
Kanungu		34
Kapchorwa	29	60

B.	Multiple seasons (Kapchorwa district)			
	2014A	2015A	2015B	Total per season
One season after trial	43	29		72
Two seasons after trial		30	20	50
Three seasons after trial			20	20

The researcher best-bet technology consisted of a combination of individual practices. For each individual practice we measured if farmers used the practice or not as a binomial variable (use or non-use) according to the criteria specified in Table 4.4. Farmers who used all individual practices were considered to use the full researcher best-bet technology. Farmers who used none of the practices were non-users of the technology. Farmers who used a selection of practices were considered to modify the technology (did not use the technology to the full threshold, cf. Brown et al., 2017). We called this an adaptation of the researcher best-bet technology. For varieties specifically, we also measured if farmers completely replaced their old variety, or if they grew the improved variety next to their old variety. The latter was defined as partial use (i.e. the new practice has not completely replaced the old practice). Over time, farmers could move between different stages: from adaptation to use or from use to non-use or adaptation.

2.4.2 Statistical analyses

Statistical analyses were performed in RStudio version 1.0.143 (R Core Team, 2017). Differences in climbing bean grain yield and the effect of the use of individual practices, planting dates and farmers' estimated soil fertility on grain yield (Section 3.3.1) were analysed with a linear mixed model with district, season and plot as fixed and farm as random factor. Grain yields were square root transformed to ensure normality of residuals. Two outliers of yields of > 8000 kg ha^{-1} on N2Africa plots were removed. Number of seeds per hole, plant density, stake density, number of plants per stake and stake length were assessed as numerical variables in this case and square root transformed to allow comparison between variables measured at different scales. The package *lmerTest* was used to detect significant differences, with an F-test for the fixed and a Likelihood Ratio Test for the random effects.

Linear models with season and district included as explanatory variables were used to assess the relationship between the total number of practices used per plot and climbing bean grain yield; yields in the adaptation trial and the use of practices one season after the trial; and farmers' evaluation of the N2Africa and own climbing bean plot (measured on a scale from 1 (not satisfied at all) to 5 (very satisfied)) and the use of practices in the season after the adaptation trial.

Planting of climbing beans and the use of practices during and one season after the adaptation trial (Table 4.4) were related to a range of explanatory variables through univariate probit analyses (Section 3.3.2). Although the decision to use a certain practice may be related to the use of another practice and a multivariate probit would be more suitable to model such interrelated decisions (Marenya and Barrett, 2007; Kassie et al., 2013), our data were too unbalanced to result in useful outcomes. Instead, we assessed the correlation between practices separately to describe complementarity (positive correlation) or substitution (negative correlation) between practices.

Table 4.4: Criteria used to define use, non-use and adaptation of the researcher best-bet technology and the individual practices composing this technology by farmers during and one or more seasons after participating in the adaptation trials

Individual practices and researcher best-bet technology	Definition
Individual practices	
Improved variety	Use = planted variety from adaptation trial package
	Non-use = planted different variety than provided in the adaptation trial package
TSP	Use = applied TSP fertilizer
	Non-use = applied no fertilizer or a different type of fertilizer (DAP, NPK)
Organic fertilizer	Use = applied animal manure, crop residues, household waste
	Non-use = applied no organic fertilizer
Sole cropping	Use = applied sole cropping
	Non-use = applied intercropping
Row planting	Use = applied row planting
	Non-use = applied random planting, broadcasting
Seeds per hole	Use = applied 2 seeds per hole
	Non-use = applied 1 or > 2 seeds per hole
Plant density	Use = applied 144,000 to 176,000 plants per ha (160,000 plants plus or minus 10%)
	Non-use = applied < 144,000 or > 176,000 plants per ha
Plants per stake	Use = applied ≤ 4 plants per stake
	Non-use = applied > 4 plants per stake
Stakes per ha*	Use = applied 36,000 stakes per ha or more (40,000 stakes minus 10%)
	Non-use = applied < 36,000 stakes per ha
Stake length*	Use = applied an average stake length ≥ 1.75 m
	Non-use = applied an average stake length < 1.75 m
Researcher best-bet technology	Use = applied all individual practices
	Non-use = did not use any of the individual practices
	Adaptation = applied a selection of individual practices

* *Practice only measured in season of adaptation trial, not in season after*

Generalized linear models with a probit link function were used for each individual practice. The function *step* with forward selection of variables was used to obtain a model per practice. Explanatory variables consisted of season, district, household, plot and agro-ecological characteristics. An overview and descriptive statistics of the explanatory variables are presented in Table 4.5. Livestock ownership was converted to Tropical Livestock Units (TLU) (Jahnke et al., 1982). Outliers of 15 and 20 TLU and farm sizes of 20 ha were removed. Farm size, TLU number of household members and age of the household head were square root transformed to ensure normality of residuals. Household characteristics were available for farmers during and after the trials, but plot characteristics only for the adaptation trials. We therefore considered two different models for the adaptation trials: one for household characteristics only (for comparison with the season after the adaptation trial), and one for the combination of all variables.

Finally, univariate probit models per practice (season and district included as explanatory variables) were used to relate planting of climbing beans and the use of practices in the season after the adaptation trial to previous experience with the cultivation of climbing beans (had farmer ever grown climbing beans before) and the use of practices (had farmer ever used the practice in climbing bean before) (Section 3.3.3).

3. Results

3.1 Use and adaptation during and one season after the adaptation trials

3.1.1 Climbing bean cultivation and use of practices

About 85% of the farmers who received seed of an improved climbing bean variety for an adaptation trial planted the seed (Fig. 4.1). Most non-planters said they would keep the seed for next season, a few farmers ate the seed or gave it away. One season after the adaptation trial, 70% of the farmers re-planted climbing beans. There were large differences between districts, however: 90-95% of the farmers in Kabale and Kanungu planted, but only 50% in Kapchorwa. About 50-60% of the farmers who planted climbing beans in the season after the adaptation trial chose to grow the same improved variety as they received for the trial, except in Kabale where this was only 14% (3 farmers). Most farmers in all three districts who continued to cultivate the improved variety after the trials grew this variety next to their old variety (partial use).

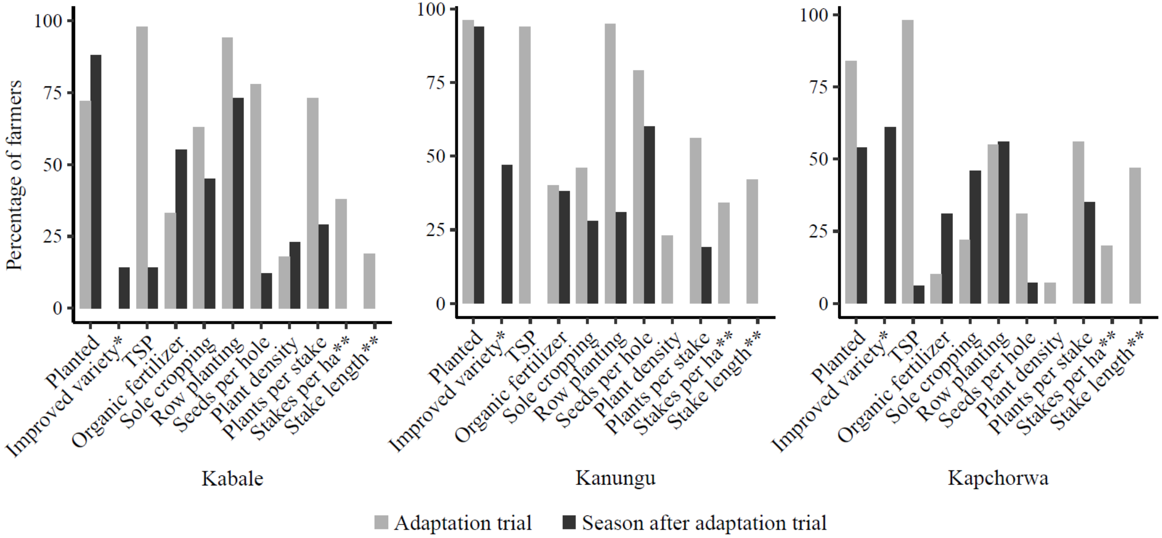
About 80% of the farmers who planted (*n*=251) received TSP as part of the adaptation trial. All but three farmers used the TSP, and another six farmers used only part of the TSP because they applied it on another crop or saved it for next season. One season after the adaptation trial the use of TSP fertilizer fell to only 3 farmers in Kabale and 3 farmers in Kapchorwa.

Table 4.5: Definitions and summary statistics (mean and standard deviation) of agro-ecological, plot and household characteristics during (*n*=374) and one season after (*n*=148) the adaptation trials per district

	Adaptation trial				One season after adaptation trial			
	Kabale (n=71)	Kanungu (n=68)	Kapchorwa (n=235)	Average (n=374)	Kabale (n=25)	Kanungu (n=34)	Kapchorwa (n=89)	Average (n=148)
Household characteristics								
Number of household members	5.5 (2.3)	5.6 (2.3)	6.7 (2.9)	6.3 (2.8)	6.9 (2.4)	5.8 (1.8)	6.4 (3.2)	6.3 (2.8)
Gender of farmer (0 = female, 1 = male)	0.3 (0.5)	0.3 (0.5)	0.4 (0.5)	0.3 (0.5)	0.4 (0.5)	0.2 (0.4)	0.3 (0.5)	0.3 (0.5)
Gender of household head* (0 = female, 1 = male)	0.9 (0.3)	0.9 (0.3)	0.9 (0.3)	0.9 (0.3)	1.0 (0.0)	1.0 (0.0)	0.9 (0.3)	0.9 (0.3)
Age household head	47 (14)	44 (15)	47 (15)	46 (15)	42 (12)	43 (14)	48 (16)	46 (15)
Education household head (0 = none or primary, 1 = secondary or higher)	0.2 (0.4)	0.1 (0.3)	0.6 (0.5)	0.5 (0.5)	0.2 (0.4)	0.2 (0.4)	0.6 (0.5)	0.5 (0.5)
Highest education in household (0=none or primary, 1 = secondary or higher)	0.6 (0.5)	0.3 (0.4)	0.9 (0.4)	0.7 (0.5)	0.7 (0.5)	0.5 (0.5)	0.9 (0.3)	0.8 (0.4)
Farm size (ha)	0.6 (0.6)	1.7 (1.5)	1.0 (1.2)	1.1 (1.5)	0.9 (0.7)	2.4 (3.8)	1.2 (1.4)	1.5 (2.3)
TLU	1.3 (0.9)	0.8 (1.1)	1.7 (1.3)	1.5 (1.3)	2.2 (4.9)	1.0 (1.3)	2.3 (2.2)	2.0 (2.5)
Months food secure (0 = < 10 months, 1 = 10-12 months)	0.7 (0.5)	0.8 (0.4)	0.4 (0.5)	0.5 (0.5)	0.5 (0.5)	0.6 (0.5)	0.6 (0.5)	0.6 (0.5)
Production orientation (0 = all or most produce consumed, 1 = half or most produce sold)	0.5 (0.5)	0.1 (0.3)	0.5 (0.5)	0.4 (0.5)	0.6 (0.5)	0.1 (0.3)	0.5 (0.5)	0.4 (0.5)
Off-farm income (0 = all or most income from farming, 1 = half or most income off-farm)	0.1 (0.3)	0.4 (0.5)	0.2 (0.4)	0.2 (0.4)	0.1 (0.4)	0.2 (0.4)	0.3 (0.4)	0.2 (0.4)

	Adaptation trial				One season after adaptation trial			
	Kabale (n=71)	Kanungu (n=68)	Kapchorwa (n=235)	Average (n=374)	Kabale (n=25)	Kanungu (n=34)	Kapchorwa (n=89)	Average (n=148)
Frequency of hiring labour (0 = never or sometimes, 1 = regularly or permanently)	0.3 (0.5)	0.5 (0.5)	0.4 (0.5)	0.4 (0.5)	0.7 (0.5)	0.8 (0.4)	0.6 (0.5)	0.7 (0.5)
Farmers with income from working on other people's fields (0 = no, 1 = yes)	0.0 (0.2)	0.2 (0.4)	0.2 (0.4)	0.2 (0.4)	0.0 (0.0)	0.1 (0.3)	0.1 (0.3)	0.1 (0.3)
Farmers with income from salary, pension or remittances (0 = no, 1 = yes)	0.1 (0.3)	0.1 (0.3)	0.3 (0.4)	0.2 (0.4)	0.1 (0.3)	0.1 (0.4)	0.2 (0.4)	0.2 (0.4)
Plot and agro-ecological characteristics								
Land tenure (1 = owned, 0 = otherwise)	0.9 (0.3)	0.9 (0.3)	0.9 (0.4)	0.9 (0.3)	-	-	-	-
Farmer perceived soil fertility (3 = good, 2 = moderate, 1 = poor)	2.3 (0.7)	2.4 (0.8)	2.5 (0.7)	2.4 (0.7)	-	-	-	-
Farmer perceived soil fertility of plot in relation to other plots (3 = better, 2 = same, 1 = poorer)	2.0 (0.8)	2.2 (0.9)	2.2 (0.7)	2.2 (0.8)	-	-	-	-
Soil depth measured up to 50 cm	34 (9)	39 (7)	47 (5)	43 (8)	-	-	-	-
Elevation (masl)	1792 (61)	1857 (105)	1862 (105)	1848 (102)	-	-	-	-
Availability of trees for staking	2.3 (0.5)	2.6 (0.5)	2.1 (0.2)	2.2 (0.4)	-	-	-	-

* *Farmers reported if they were head of the household or not*



** Planting an adaptation trial by definition meant planting the variety distributed in the adaptation trial package. The percentage of farmers using the improved variety in the adaptation trial is therefore not indicated (100% by default).*

*** The number of stakes per ha and stake length were only assessed in the season of the adaptation trial.*

Fig. 4.1: Percentage of farmers planting seed from package and using demonstrated climbing bean practices in adaptation trials (seasons 2014B, 2015A and 2015B) (n=374) and one season after the adaptation trials with their own seeds and inputs (seasons 2015A and 2015B) (*n*=148) in Kabale, Kanungu and Kapchorwa districts in Uganda.

Five out of these six farmers did not plant in the previous season and simply used the TSP that was provided in the adaptation trial. Therefore overall only one farmer in Kapchorwa bought TSP from an agro-dealer.

The use of organic fertilizer in the adaptation trials ranged from 10% in Kapchorwa to 40% in Kanungu. In the season after the trial the use of organic fertilizer increased in Kabale and Kapchorwa and remained more or less the same in Kanungu. The other management practices were generally implemented among a larger percentage of farmers in Kabale and Kanungu than in Kapchorwa during the season of the adaptation trial. In the season after the adaptation trial the differences between districts were less pronounced. The number of seeds per hole and plants per stake used by farmers were often larger than those demonstrated. Plant densities were smaller among farmers in Kanungu and Kapchorwa, but much larger in Kabale (average of 235,000 plants per ha).

Two of the management practices, stakes per ha and stake length, were only assessed during the adaptation trials and not in the season after. The demonstrated number of stakes per ha was used by 25% of the farmers. The average ranged between 27,000 stakes per ha in Kapchorwa and 34,000 stakes per ha in Kanungu. An average stake length of 1.75 m or more was only used by about 20% of the farmers in Kabale, and by 40-50% of the farmers in Kanungu and Kapchorwa. The average stake length in Kabale was 1.60 m, in Kanungu and Kapchorwa 1.74 m.

3.1.2 Researcher best-bet technology

During the adaptation trials, only two (out of 177) farmers used all seven practices of the best-bet technology that were monitored during and after the adaptation trial (TSP, organic fertilizer, sole cropping, row planting, seeds per hole, plant density and plants per stake) (Fig. 4.1). Hence, all other farmers (99%) adapted the technology yet none of the farmers used none of the practices. The average number of practices used was 3.8 and was largest in Kanungu (4.4), followed by Kabale (4.2) and Kapchorwa (3.5). If we also consider the stakes per ha and stake length, none of the farmers used the full researcher best-bet technology. In the season after the adaptation trial, the average number of practices decreased to 2.8 (2.9 in Kabale, 3.6 in Kanungu and 2.4 in Kapchorwa), but again all farmers used at least one of the practices.

3.2 Reasons for use and adaptation

3.2.1 Climbing bean cultivation

The farmers who continued the cultivation of climbing beans in the season after the adaptation trial largely mentioned good yields as positive aspect of climbing beans (80% in Kabale, 50% in Kanungu and 40% in Kapchorwa). Farmers who did not grow climbing beans after the adaptation trial mostly mentioned poor weather conditions (too much rainfall or sunshine) (32%), a lack of stakes (29%), or a lack of seed due to poor yields in the previous season or destruction of the seed during storage (27%). Almost 70% of the farmers who did not plant climbing beans in the season after the adaptation trial grew bush beans instead. Main reasons to grow bush beans instead of climbing beans were that bush beans do not require stakes (55%), and bush beans were perceived to be more tolerant to sunshine than climbing beans (32%).

3.2.2 Use of practices

Farmers who continued the cultivation of the distributed varieties often mentioned the good yield and taste of these varieties. Farmers who cultivated the new variety next to their old variety (partial use) did this because the old variety had a ready market, a good taste, the seed was more easily available (in large quantities), or the variety was more tolerant to the prevailing weather conditions. Main reasons to reject the distributed variety were the better yield (34%), market prices (19%), and tolerance to weather conditions (19% of the farmers in Kanungu) of their old variety. In Kapchorwa, farmers using either the distributed or their old variety mentioned that this variety was the only seed available.

A very common adaptation of the researcher best-bet technology was to grow climbing beans without TSP or with a different type of P-fertilizer in the season after the adaptation trial. In Kapchorwa, about 30% of the farmers used DAP instead of TSP. DAP is extensively used for maize production in the area and is widely available. The use of DAP in bean (bush or climbing) was therefore already common practice among farmers in Kapchorwa, whereas TSP was not easily available at the time of study. Farmers who did not use P-fertilizer said the soil was already fertile or that fertilizer was too expensive. Organic fertilizer was applied by about half of the farmers. The others mentioned that the soil was already fertile (36%), that their fields were far away and transport of organic fertilizer is heavy (28%), or that organic fertilizer was not available (26%).

Another adaptation, practiced by the majority of farmers in Kanungu and Kapchorwa, was to grow the climbing beans in intercropping with (coffee and) banana instead of sole cropping. A few farmers in Kanungu intercropped with maize. The main reason for intercropping was a shortage of land (mentioned by 55% and 82%, respectively). Farmers who grew beans as sole crops generally did this to get good yields and to avoid competition for water, nutrients and light from other crops. For the adaptation trials specifically, farmers mentioned that sole cropping was taught in the demonstrations (22%) or that they wanted to see how the variety would yield when grown alone (19%).

In Kapchorwa, about half of the farmers planted in rows, and in Kabale and Kanungu row planting decreased considerably in the season after the trial. The main reasons given for random planting or broadcasting were tradition, a lack of time and labour, ease of the method.

Farmers also mentioned that they had to plant in between another crop that was already there. Farmers who planted in rows mentioned that this made management (staking, weeding, spraying) easier, gave better yields, or required fewer seeds than broadcasting. During the adaptation trials, 41% mentioned that row planting was taught in the demonstration or instruction leaflet.

Also farmers who planted two seeds per hole said they learned this in the demonstration (50%). Other reasons for reducing the number of seeds per hole were to avoid congestion or competition for nutrients and sunlight, or to plant a larger area. Farmers who planted a larger number of seeds per hole mentioned tradition and to increase the chances of plant survival and to be efficient with the stakes. The latter was therefore also mentioned by farmers who applied more than four plants per stake. More than half of the farmers mentioned, however, that they just placed the stake randomly and whatever number of plants that could reach the stake would climb on it. A shortage of stakes and tradition were also mentioned. Only 10% of the farmers in Kabale and Kanungu and 35% of the farmers in Kapchorwa ever selected stakes based on their length. Others referred to the shortage of stakes and just used whatever they could get (80%), mentioned that selecting long stakes was time consuming, or saw no specific reason to select long stakes.

3.2.3. Staking of climbing beans

As the lack of stakes was mentioned as important constraint for climbing bean cultivation and alternative staking methods were offered in the demonstration, staking methods received specific attention. During the adaptation trials, single stakes were the most commonly used method by far because of tradition, the ease of the method, the cost and availability of the material and a lack of knowledge of other methods. Seven farmers in Kapchorwa used tripods (of which four in combination with single stakes) because tripods were considered stronger than single stakes or as support for weaker stakes. One farmer in Kabale used sisal strings but commented that this was “way too tiresome” and he would not use them again. Five farmers did not stake at all due to illness, a lack of time, or destruction of the beans by cows roaming through the field.

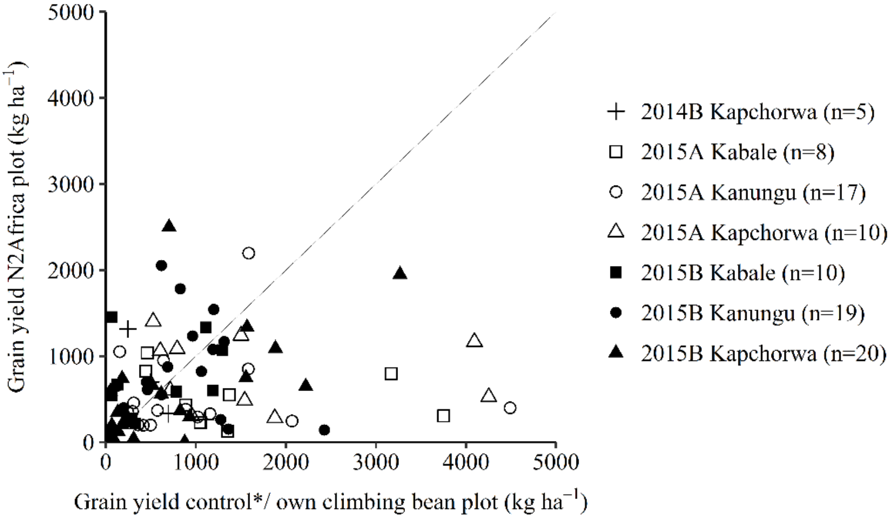
We expected an increase in the use of the staking alternatives in the season after the trial, as 30-60% of the farmers indicated that they had then seen the alternatives in the demonstration trials. All farmers used single stakes, however, in the season after the adaption trial.

3.3 Explaining diversity in climbing bean cultivation and use of practices

3.3.1 Performance of adaptation trials

3.3.1.1 Climbing bean grain yield in adaptation trials

Good or poor yields obtained in the adaptation trials were reasons mentioned by farmers to (dis)continue the cultivation of climbing beans. Climbing bean grain yields on the N2Africa and own climbing bean plot showed a large variation (Fig. 4.2). Some farms had very small yields on both plots, whereas others achieved yields of around 2500 kg ha^{-1}. Especially in Kanungu in season 2015B the N2Africa plots seemed to perform better than own climbing bean plots, but there were many cases in which the N2Africa plot performed worse than the farmers' own climbing bean plot. Average yields on the own climbing bean plot were therefore significantly larger than on the N2Africa plot in season 2015A ($P < 0.05$), but there were interactions between season and district (Table 4.6).



** N2Africa plots (without TSP) were compared with a control plot (with TSP) in season 2014B. In 2015A&B farmers planted an N2Africa plot next to their own climbing beans instead of a control plot*

Fig. 4.2: Paired observations of climbing bean grain yield (kg/ha) on control (2014B) or own (2015A&B) climbing bean plot versus N2Africa plots per season and district

Table 4.6: Average grain yields (kg ha^{-1}) of climbing bean on N2Africa and control or own plot in adaptation trials in seasons 2014B, 2015A and 2015B per district. Yields for each season + district combination were analysed separately in a linear mixed model with plot as fixed and farm as random effect, due to an interaction between season, district and yield.

	2014B			2015A			2015B		
	N2Africa	Control	*P*	N2Africa	Own	*P*	N2Africa	Own	*P*
Kabale	-	-	-	573	1236	ns	687	531	ns
Kanungu	-	-	-	545	965	ns	660	801	ns
Kapchorwa	284	513	ns	997	1686	< 0.1	843	838	ns
Average	284	513	ns	816	1233	< 0.05	739	769	ns

Although generally the N2Africa plots did not have better yields than the farmers' own climbing bean plots, the total number of practices used on the N2Africa plot showed a positive relationship with climbing bean yields of these plots in Kanungu ($P < 0.05$) and Kapchorwa (not significant) (Fig. 4.3). The number of stakes ha^{-1} was the only individual practice that had a highly significant positive effect on yield in all three districts ($P < 0.001$). Variety and row planting also tended to have an effect on yields ($P < 0.1$). Other practices such as TSP fertilizer or manure did not improve yields.

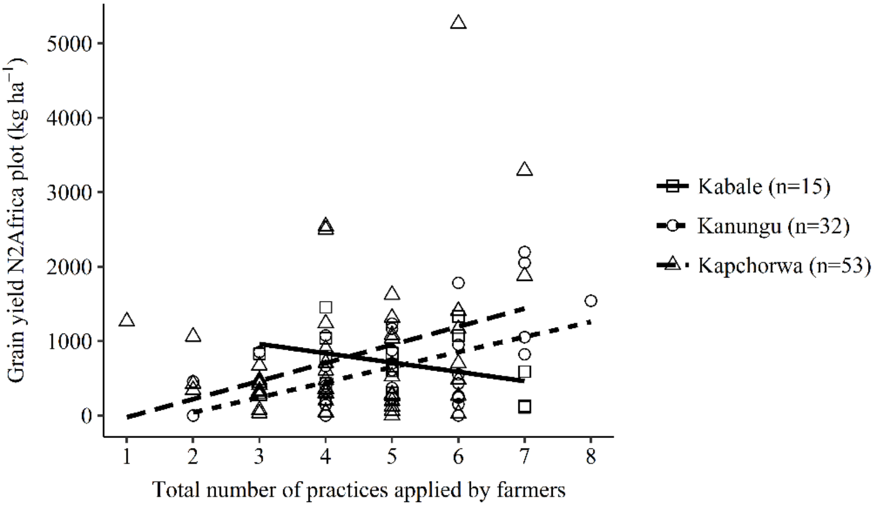


Fig. 4.3: Relation between total number of practices applied (of TSP, organic fertilizer, sole cropping, row planting, seeds per hole, plant density, plants per stake, stakes per ha and stake length) and climbing bean grain yield (kg ha^{-1}) on the N2Africa plot in adaptation trials per district. Relationship between yield and number of practices used only significant in Kanungu district (linear regression, $P < 0.01$, $R^2 = 0.23$).

The general lack of difference or even better yields on the own climbing bean plot than on the N2Africa plot could have discouraged farmers to plant climbing beans in the season after the trial. However, yields of farmers who did and did not plant climbing beans one season after the trial did not differ. Conversely, better yields with more practices could have convinced farmers to use more practices in the season after the trial, but there was no relationship between yield during and the number of practices used after the trial.

The limited improvements and in some cases reduced yield on the N2Africa plot compared with the own climbing bean plot were not anticipated. In the demonstration trials in the same districts and seasons (data not presented), the combination of TSP and manure improved climbing bean yields ($P < 0.05$), and the increase in yields tended to be larger in improved than in local varieties (not significant). Manure and TSP only had positive effects as well, but these were not significant.

One explanation for the lack of yield improvement could be the late delivery of seed for the adaptation trial, often mentioned by farmers. More than a third of the farmers planted the N2Africa plot later than the own climbing bean plot, but there was no relationship between planting date and yield of the N2Africa plot or the own climbing bean plot. Planting dates were only available for 50% of the farmers, however, and not for Kapchorwa and Kabale (only 3 data points) in 2015A. In season 2015B (the season with the most data points available), there was a non-significant negative relationship between planting date and yield. Based on this, we cautiously conclude that the late arrival of seeds is one reason for the N2Africa plots performing worse than the own climbing bean plots that were planted earlier. Another reason could be that farmers decided to plant the N2Africa plot on relatively poorer fields than their own climbing beans. However, farmers' indication of the (relative) fertility of the field had no effect on yield.

Farmers were also asked to explain the difference in yield between the two plots. Poor yields on the N2Africa plot were attributed to pests and diseases, weather conditions (too much rainfall, drought), damage by cows, goats or chickens and late planting. Good yields on the own climbing bean plot were often attributed to varieties: farmers' own varieties were considered more resistant to weather conditions or pests and diseases. If yields on the N2Africa plot were larger, farmers mentioned the application of mineral or organic fertilizer and the use of other improved practices (number and length of stakes, row planting).

3.3.1.2 Evaluation of adaptation trials

Farmers judged the trial and the different practices not only based on yields, but also on other aspects. In general, scores for the N2Africa plot were quite similar to their own climbing bean plot (Fig. 4.4). Grain size was the only aspect that scored better on the N2Africa than on the own plot ($P < 0.05$), although fodder yield and tolerance to pests other than insects tended to be better as well ($P < 0.1$). For marketability, the improved varieties scored worse than farmers' own varieties.

The evaluations had limited predictive value for the use of practices in the season after participation in the trials. In general, farmers who planted climbing beans after the trials gave a significantly lower score for the marketability of the variety planted on the N2Africa plot than farmers who did not plant ($P < 0.05$). The farmers who continued cultivating the distributed varieties gave a significantly better score for the resistance to diseases (blight, anthracnose) of these varieties than farmers who did not plant. There were no significant relationships between the scores for costs and availability of inputs and the use of P-fertilizer.

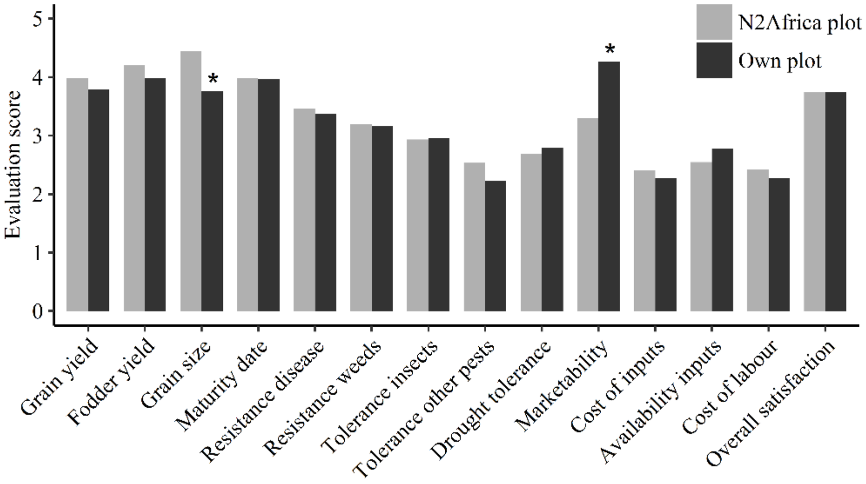


Fig. 4.4: Farmers' evaluation of the N2Africa plot and the own climbing plot in adaptation trials in seasons 2015A and 2015B (*n*=152). Scores ranged from 1 (not satisfied at all) to 5 (very satisfied). * indicates significant difference in evaluation score between N2Africa and own climbing bean plot (One-way ANOVA, $P < 0.05$).

3.3.2 Household, plot and agro-ecological characteristics

Apart from performance of the trial, household characteristics were also expected to constrain or facilitate the cultivation of climbing beans and the use of practices. Planting of climbing beans during[1] and after the adaptation trial showed a negative relationship with education of the household head; income from salary, pension or remittances and food security (Table 4.7). On the other hand, the relationship with farmers working on other people's fields for income was positive. These variables are all proxies for farmers' wealth, and suggest that planting was often done by poorer farmers. An exception was the positive relationship with the highest education level in the household.

Farmers in Kapchorwa planted climbing beans significantly less often in the season after the trial than in Kabale, but continued to grow the variety received in the adaptation trial package more often. The use of the improved variety was associated with larger farm sizes, but with poorer education of the household. TSP could not be considered as almost all farmers applied TSP during the adaptation trials, and almost none in the season after. Organic fertilizer was applied more often by female farmers, by farmers with larger farms and with better education.

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[1] Household characteristics for farmers who did not plant the adaptation trial only available in season 2014B; in 2015A and 2015B only collected for farmers who planted the trial. Results presented are for season 2014B only.

Table 4.7: Coefficient estimates of household (hh) characteristics related to the use of practices during (*n*=374) and one season after (*n*=148) adaptation trials, tested with a univariate probit model and selected with the function *step*.

	Adaptation trials		One season after adaptation trials	
Planted[1]	Education hh head	-1.184*	District Kanungu	0.659
	Income casual labour on-farm	0.723 **.**	District Kapchorwa	-0.798 **.**
	Income salary/pension/ remittances	-0.635 **.**	Food security	-0.515 **.**
	Highest education in hh	1.251 **.**		
Improved variety[2]	-		District Kanungu	0.450
			District Kapchorwa	1.252*
			Farm size	0.633 **.**
			Highest education in hh	-0.996*
			Season 2015B	-0.797 **.**
			No of hh members	0.377
Organic fertilizer	District Kanungu	0.372	Season 2015B	1.443**
	District Kapchorwa	-1.055**	TLU	0.842**
	Gender of farmer	-0.900**	Age	-0.399*
	Farm size	0.540*		
	Gender hh head	-0.858*		
	Education hh head	0.501 **.**		
Sole cropping	District Kanungu	-0.339	Season 2015B	-0.848*
	District Kapchorwa	-1.089**		
	Season 2015A	-0.643*		
	Season 2015B	-0.066		
	Hired labour	0.445*		
Row planting	Farm size[3]	1.116	Season 2015B	-11.000
			District Kanungu	-1.068*
			District Kapchorwa	-0.898**.**
			Gender hh head	5.243
Seeds per hole	District Kanungu	0.057	Season 2015B	2.096**
	District Kapchorwa	-1.438**	District Kanungu	1.591**
	TLU	0.569**	District Kapchorwa	0.944*
	Hired labour	-0.489*		

	Adaptation trials		One season after adaptation trials	
Plant density	Season 2015A	4.541	TLU	-0.463 .
	Season 2015B	5.183		
	Farm size	0.599*		
	Gender hh head	0.710		
Plants per stake	Hired labour	-0.305 .	Season 2015B	-1.657**
			Gender of farmer	0.813*
			Number of hh members	-0.855*
			TLU	0.702*
Stakes per ha[4]	Season 2015A	1.176**	-	
	Season 2015B	0.811*		
	Hired labour	-0.553*		
	Gender of farmer	0.405*		
	Off-farm income	0.459*		
Stake length[4]	Number of hh members	0.368*	-	
	Income salary/pension/ remittances	0.458*		
	District Kanungu	0.704*		
	District Kapchorwa	0.519 .		
	TLU	0.272		

Note: TSP was not considered as observations of farmers (not) applying TSP were too few.

[1] *Household characteristics for farmers who did not plant the adaptation trial only available in season 2014B; in 2015A and 2015B only collected for farmers who planted the trial. Results presented are for season 2014B only.*

[2] *All farmers who planted the adaptation trial used the variety distributed in the package, so explanatory variables for planting the trial and use of the improved variety are the same.*

[3] *(Almost) all farmers planted in rows in Kabale and Kanungu during the adaptation trials – results presented are for Kapchorwa only.*

[4] *Practice only measured in season of adaptation trial, not in season after.*

. *Statistical difference at* $P < 0.1$

* *Statistical difference at* $P < 0.05$

** *Statistical difference at* $P < 0.01$

Livestock ownership and organic fertilizer were only positively related in the season after the trial. The other practices largely differed between seasons and districts. For instance, almost all farmers in Kabale and Kanungu planted in rows during the adaptation trials and only farmers in Kapchorwa planted randomly. In the season after the trial, however, all farmers in Kapchorwa in season 2015A planted in rows. In season 2015B results were mixed again in all three districts. Relationships with household characteristics were often inconsistent: the demonstrated number of seeds per hole was applied more often by farmers with more TLU, but less often by farmers who hired labour frequently. Likewise, plant density was positively related to farm size during the adaptation trial, but negatively with TLU in the season after. The relationship with gender of the farmer was often positive, meaning that male farmers generally applied more practices than female farmers.

Plot and agro-ecological characteristics (assessed in combination with household characteristics) also played a role in the use of most practices during the adaptation trials (data not presented). Organic fertilizer was applied to fields with larger soil depth ($P < 0.1$), sole cropping had a negative ($P < 0.05$), and the number of seeds per hole a positive ($P < 0.1$) relationship with ownership of the land, row planting (Kapchorwa district only) was mostly done at lower elevation ($P < 0.01$), and the demonstrated plant density was more often applied at higher elevation ($P < 0.05$). The number of stakes per ha and stake length were not related with any of the plot or agro-ecological characteristics. Only in the case of sole cropping, the selected plot and agro-ecological characteristics had a more significant contribution than household characteristics.

Farmers used several practices at the same time during the adaptation trials: there was a significant positive correlation between the use of organic fertilizer, sole cropping, row planting, the demonstrated number of seeds per hole and plant density (Table 4.8). In the season after the trial, however, row planting had a strong negative relationship with the number of seeds per hole and plant density. Observations of the latter practices were few, however. Farmers who planted the demonstrated number of seeds per hole in the season after the trial also continued planting of the improved variety and used TSP, sole cropping and row planting more often, but did not use the demonstrated number of seeds per hole and plant density.

3.3.3 Previous experience with the technology

Farmers had different previous experience with climbing bean cultivation. All farmers in Kabale and Kanungu monitored one season after the adaptation trial indicated that they had ever grown climbing beans before, but in Kapchorwa only 70% of the farmers. The other practices were new to 50-100% of the farmers. Previous experience influenced the use of practices: farmers who had already used a practice in climbing beans before often used this practice more frequently than farmers for whom the practice was new (Fig. 4.5). Organic fertilizer and the demonstrated number of plants per stake were used significantly more often, and farmers who had already grown climbing bean before also tended to grow them more often than farmers for whom they were new. The latter were mainly the farmers in Kapchorwa.

Table 4.8: Correlation coefficients of use of climbing bean production practices during and one season after adaptation trials

	IV	TSP	OF	SC	RP	SEH	PD	PS	STH2	SL2
Adaptation trials										
IV[1]	-									
TSP	-	-								
OF	-	0.08	-							
SC	-	0.06	0.31**	-						
RP	-	-0.02	0.20**	0.31**	-					
SEH	-	0.05	0.24**	0.23**	0.36**	-				
PD	-	0.06	0.24**	0.16*	0.14	0.19**	-			
PS	-	0.02	-0.05	-0.05	-0.05	0.24**	0.00	-		
STH[2]	-	0.10	0.06	0.15	0.14	0.07	0.06	0.03	-	
SL[2]	-	0.06	-0.15*	-0.04	-0.08	-0.06	0.00	0.06	-0.04	-
One season after adaptation trials										
IV[1]	-									
TSP	0.18	-								
OF	-0.05	-0.01	-							
SC	0.07	0.11	-0.10	-						
RP	0.23*	0.19	-0.01	0.26**	-					
SEH	-0.17	-0.09	-0.02	-0.19	-0.94**	-				
PD	-0.13	0.14	-0.04	-0.15	-0.70**	0.67**	-			
PS	0.23*	0.29**	0.00	0.31**	0.58**	-0.55**	-0.30**	-	-	-

IV = improved variety, TSP = TSP fertilizer, OF = organic fertilizer, SC = sole cropping, RP = row planting, SEH = seeds per hole, PD = plant density, PS = plants per stake, STH = stakes per ha, SL = stake length

[1] *All farmers who planted the adaptation trial used the variety distributed in the package, so not considered for adaptation trials*

[2] *Practice only measured in season of adaptation trial, not in season after.*

* *Statistical difference at* $P < 0.05$

** *Statistical difference at* $P < 0.01$

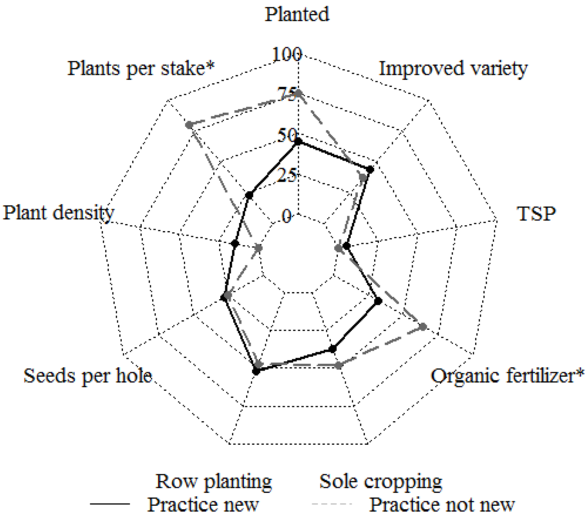

Fig. 4.5: Percentage of farmers using individual practices one season after the adaptation trials with their own seed and inputs, by farmers for whom practice was new or not new when introduced in adaptation or demonstration trial (*n*=148). Practices marked with * indicate significant differences ($P < 0.05$) between farmers for whom practice was (not) new (assessed with univariate probit model).

3.4 Use and adaptation over time

Given that previous experience resulted in a more frequent use of practices, a consistent or even incremental use of practices over time was expected. A sub-group of farmers in Kachorwa was followed up to two (50 farmers) or three seasons (20 farmers) after the adaptation trial. These were mostly farmers from two sub-counties[2] where climbing beans were not grown before (for 84% of farmers, climbing beans were new). About half of the farmers of this sub-group planted climbing beans in the first season after participation in the adaptation trials, but only 30% planted in the second season and 25% in the third season (Fig. 4.6). A lack of seed and drought were the most frequently mentioned reasons not to plant climbing beans. The use of the distributed varieties remained relatively constant at about 55-75%. The use of TSP decreased, but about 30% of the farmers in all three seasons used DAP. One farmer explicitly mentioned that he used DAP because TSP was not available. The percentage of farmers planting the beans as sole crops decreased from 70% to less than a quarter of the farmers over the seasons. The demonstrated number of seeds per hole and plant density were applied by very few farmers (the increase in the third season concerned only one out of three farmers with data for this variable), but the use of the demonstrated number of plants per stake increased over the seasons.

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[2] Kapchesombe and Kaptanya sub-counties

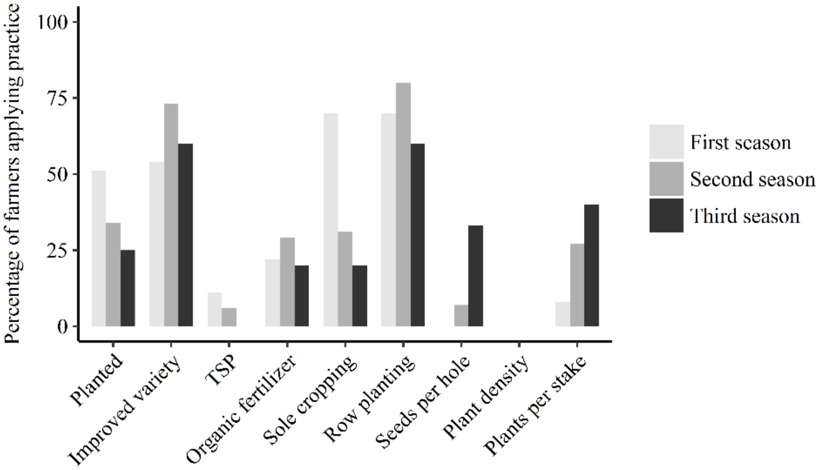


Fig. 4.6: Subset of farmers in Kapchorwa district who planted climbing beans and applied individual practices one (*n*=63), two (*n*=50) and three (*n*=20) seasons after participation in the adaptation trials (using their own seed and inputs).

All farmers in the first and second season used single staking, but in the third season one farmer used strings and indicated that this was due to a lack of stakes. The total number of best-bet practices applied remained stable between the first, second and third season after participation in the adaptation trial with an average of 2.2, 2.4 and 2.2 practices respectively, and none of the farmers used the full researcher best-bet.

The use of practices by individual farmers was not consistent over the seasons, i.e. the same farmer could use a practice during the first season, but not in the second or *vice versa*. From the 50 farmers that were monitored for two seasons, about a quarter of the farmers planted both in the first and second season, and about 50% planted in one of the two seasons (Fig. 4.7). TSP was not used in any of the seasons by about 90% of the farmers, and organic fertilizer by 75%. All farmers practiced row planting in one of the two seasons. The majority of farmers (75-100%) did not use the demonstrated number of seeds per hole, plant density and plants per stake in any of the seasons.

In the third season only five out of 20 farmers planted, and only three had planted climbing beans in all three seasons. About 40% did not plant in any of the seasons. From the three farmers who planted all three seasons, one farmer applied several practices (sole cropping, number of seeds per hole) consistently throughout the seasons. The other four farmers who planted in the third season switched practices (and planting of climbing beans) between seasons. The analysis over time therefore showed that the use of practices was often inconsistent and not necessarily incremental.

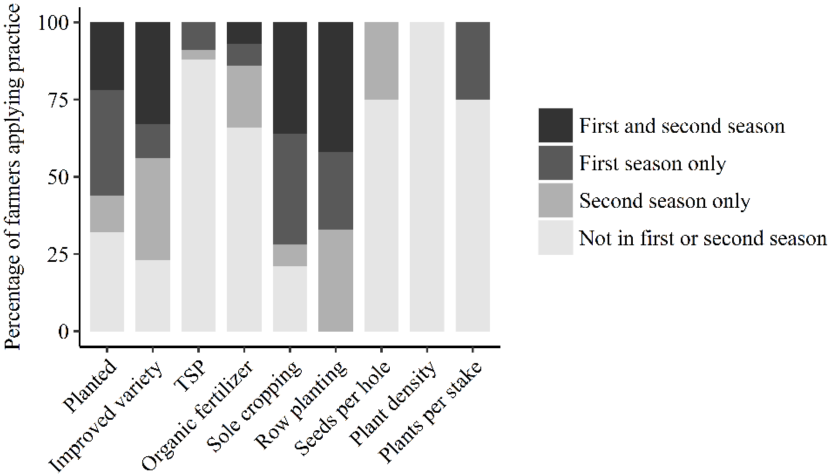


Fig. 4.7: Subset of farmers in Kapchorwa district who were monitored for two seasons after the adaptation trials (*n*=50), and percentage of these farmers who planted climbing beans and applied individual practices in the first and second, first or second, or none of the two seasons after participation in the adaptation trials (using their own seed and inputs).

4. Discussion

4.1 Differences in climbing bean cultivation

Climbing bean cultivation differed between districts (Fig. 4.1, Table 4.7): 80-95% of the farmers in Kabale and Kanungu planted climbing beans in the season after the adaptation trials, but only half of the farmers in Kapchorwa. These differences point to the influence of a mixture of agro-ecological and socio-economic factors. First, farmers mentioned staking as an important constraint in Kapchorwa. The availability of trees for staking is poor in Kapchorwa district compared with Kabale and Kanungu (cf. Table 4.5). This is the result of a larger population pressure and more severe deforestation in Kapchorwa. Farmers in Kapchorwa were allowed regulated access to Mt Elgon forest, but at the time of study the agreement just had to be renewed and the forest was temporarily closed off which exacerbated problems of access to stakes. Especially in Kanungu, farmers often owned plantations of *Eucalyptus* or *Grevillea* where they (and their neighbours) can easily extract stakes.

Second, farmers in Kabale and Kanungu in southwestern Uganda already had a longer history of climbing bean cultivation (Table 4.1). This is related to the work of organisations such as the Pan-African Bean Research Alliance (PABRA) (Buruchara et al., 2011), Uganda's National Agricultural Research Organisation (NARO), and the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) (Mcharo and Katafiire, 2014), focusing on the dissemination of new varieties, seed systems and the organisation of producer groups. Southwestern Uganda has become the main production area of climbing beans in Uganda. The same organisations have worked with climbing beans in eastern Uganda, but mainly on the western instead of the northern slopes of Mt Elgon where Kapchorwa district is situated. The shorter history of climbing bean cultivation in Kapchorwa also led to a lack of seed of the distributed varieties, which made the continuation of climbing bean cultivation more difficult than in southwestern Uganda. Lack of seed is an often cited problem particularly with legume crops (David et al., 2002; Shiferaw et al., 2008).

Differences in climbing bean cultivation within districts were related to household characteristics and farmers' previous experience with climbing bean cultivation. Both during and after the adaptation trials, household characteristics that are often associated with poorer farmers had a positive relationship with climbing bean cultivation. This is in line with earlier findings in Rwanda (Sperling and Muyaneza, 1995): although climbing beans require a considerable investment in capital and labour for staking and such investments often lead to use by wealthier farmers (Marenya and Barrett, 2007; Pircher et al., 2013; Grabowski et al., 2016), climbing beans are considered beneficial for poorer farmers because their yield potential allows intensification on small pieces of land. The more frequent planting of climbing beans by farmers who had already grown climbing beans before may indicate that farmers first need to find a specific 'niche' in time and space within their farm, try the beans out for a few seasons and then decide whether to continue growing them (Sperling and Loevinsohn, 1993; Hockett and Richardson, 2016).

Finally, we expected that improvements in yield in the adaptation trials resulting from the use of the improved production practices would encourage farmers to plant climbing beans in the season after. However, we observed a large variability in yield, and farmers' own climbing bean plots yielded better than the N2Africa plots in some seasons and sites. This might lead to questions about the suitability of the technology for the area, as 'biophysical relevance' is the most frequently mentioned factor influencing the adoption of legumes (Farrow et al., 2016). However, variability in yields and responses to the different practices is common in on-farm trials (Franke et al., 2016; Ronner et al., 2016; Van Vugt et al., 2017). Moreover, responses to practices in the demonstrations and good yields on farmers' own fields indicate that the technology can perform well. Late planting of the N2Africa plot is a more likely cause for the lack of response, and reflects the logistical challenges for timely supply of inputs in large-scale projects like N2Africa. Late planting probably also explained other problems referred to by farmers: pests and diseases, and destruction by stray animals that are normally tied early in the season when everybody plants. According to our analysis, trial performance did not affect farmers' decisions to plant climbing beans in the season after the trial.

4.2 Differences in use of practices

The use of practices widely differed between seasons and districts. Relationships with farm size, labour, education, gender, access to credit and land tenure – common determinants of adoption (Feder and Umali, 1993; Doss, 2006) – were found. Only farm size had a consistent, positive relationship with a number of practices. Access to labour and higher education levels were expected to be positively related to the use of practices as well (Snapp et al., 2002a; Pender and Gebremedhin, 2008; Mugwe et al., 2009), but results were mixed (cf. Knowler and Bradshaw, 2007). Male farmers generally used practices more often than female farmers, which is in line with many other studies (Doss, 2001; Pircher et al., 2013; Peterman et al., 2014) and suggests that male farmers have better access to household resources. Only organic fertilizer was used more often by women farmers and female headed households, in contrast to findings of Ndiritu et al. (2014).

Relationships with household characteristics that could serve as proxies for wealth or access to credit (e.g. farm size, livestock ownership, off-farm employment and income from salary, pension or remittances) were again contrasting and inconsistent between seasons. As farmers changed practices from season to season, the latter is not surprising. Similar conclusions were drawn by Hockett and Richardson (2016), Marenya and Barrett (2007) and Misiko and Tittonell (2011): farmers experiment for a few seasons and rapidly change between practices based on performance or seasonal variations in weather, pests and diseases and access to resources. These changes may also be related to the nature of the practices that we studied: unlike investments in e.g. soil and water conservation, decisions on variety, use of fertilizer or plant density can be made on a seasonal basis. It also explains the limited relationship with land tenure, often found in studies related to longer term investments in soil improvement (Besley, 1995; Kerr et al., 2007). The lack of relationship between availability of trees for staking and stake density and length was surprising, but it may be that farmers with poor stake availability did not plant at all.

The inconsistency in use of practices over seasons contrasts with the common assumption that farmers increase the use of practices over time (Byerlee and De Polanco, 1986; Leathers and Smale, 1991) and gradually move towards adoption of the researcher best-bet. Although we found that farmers with previous experience used practices more often, this may rather be related to 'path dependence' – the use of practices may be dependent on earlier choices (Cowan and Gunby, 1996). Farmers who have already invested in stakes will find it easier to plant climbing beans again, or the other way around: switching to a new variety will be difficult when few farmers are growing the new variety and there is no market yet. The latter was reflected in farmers' poorer evaluation of the marketability of the new varieties. This seemed to be a temporary problem, however, as farmers indicated in later visits that market demand for the improved varieties had increased.

Finally, similar to findings in Feder and Umali (1993), Kassie et al. (2015) and Marenya and Barrett (2007), the use of practices was often interrelated. The only practices that were complementary both during and after the adaptation trials were row planting and sole cropping, and plant density and the number of seeds per hole. Farmers who intercrop climbing beans with coffee or banana will often plant wherever there is space, so sole cropping appeared better suitable for row planting.

4.3 Implications for technology re-design

Farmers used different combinations of practices, and only 1% of the farmers copied the full researcher best-bet technology. In other words, 99% of the farmers adapted the technology in one way or another. This is comparable to uptake of other complex technologies like Conservation Agriculture, where farmers also adopted only components of the technology, and adaptations were not consistent among farmers (Baudron et al., 2007; Andersson and D'Souza, 2014; Pedzisa et al., 2015).

Some adaptations related to the cultivation of climbing beans by poorer farmers. For instance, farmers with smaller farms and less livestock applied the improved variety and organic fertilizer less frequently, and farmers who relied mostly on farm income and did not have income from salary, pension or remittances used fewer and shorter stakes. These adaptations hold important information that can inform the re-design of technologies (Versteeg et al., 1998; Collinson, 2000; Hockett and Richardson, 2016), and of the technology development process (Pircher et al., 2013; Tadesse et al., 2017). Composing a ‘basket of options’ suitable for farmers of different wealth and access to resources will be more useful than offering ‘fixed’ technology packages. For instance, the farmers who continued cultivating the distributed climbing bean varieties largely used them without fertilizer. This makes a comparison of local and improved varieties, both grown with and without fertilizer, a better basis for decision for farmers than a demonstration trial with improved varieties with fertilizer only (cf. Falconnier et al., 2017). The fact that many farmers grew climbing beans in intercropping instead of sole cropping may require the assessment of varieties in intercropping, which could result in breeding of varieties for intercropping conditions (Isaacs et al., 2016), tailored fertilizer recommendations for intercropping in relatively well-managed home gardens versus sole cropping on less fertile outfields (Vanlauwe et al., 2014a), or specific management recommendations such as pruning of banana to enhance light availability for climbing beans (Ntamwira, 2013). The testing of and feedback on these options by farmers is an important part of the re-design process and helps to increase the relevance of the technology for its users (Misiko and Tittonell, 2011; Isaacs et al., 2016; Falconnier et al., 2017). Our study revealed, for instance, why some options such as the alternative staking methods were rarely used: strings were considered more expensive and labour intensive than single stakes so it turned out that strings were not ideal for poorer farmers after all.

4.4 Implications for recommendation domains and measurement of adoption

Understanding the diversity in climbing bean cultivation and the use of practices can be useful for the development of recommendation domains (a group of farmers with similar circumstances eligible for the same recommendation, Harrington and Tripp, 1984). These domains can be used for outscaling of technologies and the prediction of success among different groups of farmers. Based on our study and the differences between eastern and southwestern Uganda we could delineate broad domains related to tree cover, population pressure and opportunities for off-farm employment to suggest areas that are more or less likely to achieve high adoption rates of climbing beans. Within these domains, we found some significant relationships with household characteristics: poorer farmers cultivated climbing beans more often but used fewer of the best-bet practices, and male farmers generally used more practices than female farmers. Other relationships were variable or inconsistent, however, and farmers changed practices from season to season. This diversity questions the practical applicability of recommendation domains for specific farm types. Rather, it confirms the relevance of developing a 'basket of options' from which farmers can choose.

The diversity in use of practices also underlines the argument that adoption is not a linear, dichotomous or "once-and-for-all" process (Glover et al., 2016). For understanding the adoption process, the dynamics (i.e. through panel studies, Doss, 2006), and adaptations or different intensities of adoption (Pedzisa et al., 2015; Glover et al., 2016; Brown et al., 2017) provide more valuable information than a cross-section of farmers surveyed at one point in time. Moreover, the large variability in yields (Fig. 4.2 and 4.3) illustrates that measuring impact or returns on investment is even more complicated than measuring adoption rates.

5. Conclusion

An average of 70% of the farmers continued the cultivation of climbing beans in the season after participation in an adaptation trial. Poor weather conditions and a lack of stakes or seed were the most frequently mentioned reasons for discontinuation of climbing bean cultivation, of which only the lack of stakes can be considered a negative attribute of the technology itself. Staking is a common constraint for climbing bean cultivation, and although alternative staking materials were demonstrated to farmers in this study, their poor uptake does not suggest that this constraint can easily be overcome. The lack of seed requires specific attention for seed systems for (improved) climbing bean varieties.

Late planting reduced the performance of the adaptation trials and reflects logistical challenges associated with large-scale dissemination projects. Trial performance did not seem to affect climbing bean cultivation or the use of practices, however. Differences between districts including tree cover, population pressure and opportunities for off-farm income played a more important role and could be used as basis for broad recommendation domains for the cultivation of climbing bean. Differences within districts and inconsistent relationships with household characteristics complicated the prediction of use of practices among farmers. This warrants the development of a basket of options from which farmers may select the practices that they consider most relevant for their particular circumstances in any given season. Our results show how adoption of technologies consisting of multiple components is a complicated process that is hard to capture through the measurement of an adoption rate at one point in time.

Acknowledgements

We thank the Bill & Melinda Gates Foundation for partnering in this research through a grant to Wageningen University to support the project N2Africa: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (www.N2Africa.org). We also thank the farmers, extension officers and dissemination partners (Africa 2000 Network, VECO) in eastern and southwestern Uganda, MSc students Eva Thuijsman, Laurie van Reemst, Jan Hüskens and Wytze Marinus from Wageningen University in the Netherlands and Muranda Ezakiel, Bugingo Collins and Ajio Florence from Makerere University in Uganda and the N2Africa-Uganda team for their cooperation in data collection. A special thanks to N2Africa field liaison officers John Ssekamwa and Justine Onyinge for their conscientious assistance.

Chapter 5

How do climbing beans fit in farming systems of the eastern highlands of Uganda? Understanding opportunities and constraints at farm level

This chapter is submitted to Agricultural Systems as:
Ronner, E., Descheemaeker, K., Marinus, W., Almekinders, C.J.M., Ebanyat, P., Giller, K.E., (under review), How do climbing beans fit in farming systems of the eastern highlands of Uganda? Understanding opportunities and constraints at farm level. Agricultural Systems.

Abstract

Climbing beans offer potential for sustainable intensification in the East-African highlands, but their introduction requires a major change in the cropping system compared with the commonly grown bush bean. We explored farm-level opportunities, constraints and trade-offs for climbing bean cultivation in the eastern highlands of Uganda. We established current food self-sufficiency, income, investment costs and labour, and assessed the *ex-ante*, farm-level impact of four climbing bean options on these indicators. Input for this assessment were a detailed characterization of 16 farms of four types, and on-farm, experimental data of adaptation trials of climbing bean. Climbing beans generally improved food self-sufficiency and income, but often required increased investment and always demanded more labour than current farm configurations. Opportunities for integration of climbing beans on small farms were limited. Although some of the poorest farmers accrued the largest absolute benefits from climbing beans, it is questionable if they are able to make the necessary investments. The analysis was translated into a simple-to-use modelling tool to enable participatory analysis of the outcomes with farmers of the four farm types to understand their perspectives and decision-making. The discussions revealed a recent increase in market prices for climbing bean resulting in growing interest in their cultivation in the eastern highlands. A lack of seed and stakes was limiting climbing bean cultivation, and a sufficient amount of climbing bean seed needs to be ensured through strengthening of farmer cooperatives and improved storage.

Keywords: *Phaseolus vulgaris*, legumes, smallholder, participatory, multi-criteria

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is an important staple crop in the East African highlands providing an important source of protein, calories, minerals and vitamins. While bush varieties have been widely grown in the region for centuries, climbing bean varieties were introduced through a targeted breeding programme in Rwanda since the mid-1980s (Sperling and Muyaneza, 1995; Franke et al., 2016). Climbing beans have a better yield potential (up to 4 to 5 tons ha^{-1}), produce more biomass and fix more nitrogen than bush beans (Bliss, 1993; Wortmann, 2001; Ramaekers et al., 2013). Especially in areas of high population pressure and small farm sizes, climbing beans offer great potential for agricultural intensification. In southwestern Uganda, just across the border with Rwanda, climbing beans have now largely replaced bush beans. In eastern Uganda, on the slopes of Mount Elgon, cultivation is less widespread (Ronner et al., 2017).

Compared with bush beans, climbing beans require a major change in cropping system: bush beans are mostly grown in intercropping with maize, but climbing beans have a more prolific growth and smother the maize when planted at the same time (unlike at cooler, high elevations in Latin America, where maize and climbing bean intercropping is common (Davis and Garcia, 1983; Clark and Francis, 1985). Climbing beans are therefore better grown as sole crops, which means that, in land scarce areas, they are likely to replace existing crops. Climbing beans also need to be staked, requiring additional labour and capital (Sperling and Muyaneza, 1995; Musoni et al., 2014; Ruganzu et al., 2014). Such disadvantages may be barriers to adoption.

At field level and in terms of agronomic criteria, the benefits of climbing bean over bush bean are clear and the potential of climbing beans has been evaluated in on-farm trials (Franke et al., 2016; Ronner et al., 2017). At farm level, considering the potential replacement of existing crops and criteria other than yield (economic benefits, costs, labour), the comparison may show a different picture (cf. Sperling and Muyaneza, 1995). Moreover, given the heterogeneity of African smallholders (Giller et al., 2011), advantages and disadvantages of climbing bean cultivation are likely to differ between farms. Such farm-level differences have not been studied before. The diversity of farmers can be captured in farm typologies which help to disaggregate impacts and opportunities for different types of farmers (Tittonell et al., 2010; Franke et al., 2014; Descheemaeker et al., 2016b). A farm-level, multiple criteria exploration could therefore offer insight in the opportunities and trade-offs of climbing bean cultivation for a diversity of farmers.

Discussing the outcomes of such explorations with farmers provides quantitative feedback to farmers about their farming system, and enriches researchers' insights in farmers' priorities and constraints (Defoer, 2002; Falconnier et al., 2017). While researchers may focus on advantages in yields or costs and benefits of a particular crop, farmers may have different priorities based on the allocation of resources over multiple crops on their farm and off-farm activities (Collinson, 2001). An *ex-ante* assessment of which farmers are likely to benefit and how priorities at farm level could hinder or foster climbing bean cultivation could inform rural development projects that aim to expand climbing bean cultivation to new areas.

The objective of this study was to identify farm level opportunities, constraints and trade-offs for climbing bean cultivation among smallholder farmers in eastern Uganda with an *ex-ante* impact assessment tool. Based on a farm typology and detailed farm characterizations we established farmers' current situation in terms of the farm-level indicators food self-sufficiency, income, investment costs and labour. We analysed the effects of four different options for the integration of climbing beans on these indicators. The outcomes of this analysis were discussed with farmers, to understand their priorities, constraints and decision making with respect to climbing bean cultivation. We hypothesized that sole cropping of climbing beans with wooden stakes would provide the largest increase in food self-sufficiency and income, but also the largest trade-offs in terms of investment costs and labour, and that this would therefore not be the most preferred option among farmers.

2. Methodology

2.1 Study area and climbing bean dissemination

The study was conducted in Kapchorwa District, located on the northern side of Mt Elgon between 34.30° and 34.55° East and 1.18° and 1.50° North at an elevation of 1500 to 2200 metres above sea level (masl). The district can be divided in an 'upper' and 'lower belt', with the tarmac road situated around 1900 masl as a rough divide. Annual rainfall in the district averages 1600 mm and falls over two rainy seasons: a long season from March to July (Season A) and a shorter season from September to December (Season B). Nitisols are the dominant soil type.

A climbing bean dissemination campaign started in 2013 in two sub-counties (Kapchesombe and Kaptanya) of Kapchorwa district where climbing beans were new to many farmers. Improved varieties of climbing beans were planted with manure, phosphorus fertilizer and best management practices (row planting, plant and staking density, weeding) in small demonstrations on farmers' fields. In 2014, the campaign extended to two other sub-counties, Tegeres and Chema, in the same district. In these two sub-counties, climbing bean cultivation was more common, but with local varieties and largely without mineral fertilizer or manure. The dissemination approach changed from small demonstrations on a limited number of farmers' fields to parish-level demonstrations on visible locations (road junctions, close to schools/ churches), in combination with larger numbers of farmers trying out technologies on their own field in so-called adaptation trials.

2.2 Rapid and detailed farm characterization

The study was conducted in Chema sub-county in the first rainy season of 2014 (Season 2014A), just before the extension of the dissemination campaign to this sub-county. Chema was selected as an area of 'intermediate' climbing bean cultivation compared with neighbouring sub-counties (stakeholder interviews, 2014), which allowed a comparison between households which did and did not cultivate climbing beans. To describe the diversity of farmers in Chema, we developed a farm typology based on the approach used by Franke et al. (2014). A rapid farm characterization survey was conducted in which 75 households were interviewed with questions on household size and composition, education, land and livestock ownership, production orientation, labour hired, sources of income, valuable goods owned, type of housing, food security and crops cultivated. Stratified random sampling was applied, whereby in each of the four parishes in the sub-county at least one village was selected (five villages in total). Households within the village (n=15) were randomly selected. To develop farm types, all 75 farmers were first ranked based on landholding. Next, additional distinguishing criteria including livestock ownership, type of housing, valuable assets, production orientation and most important sources of income were used for the manual grouping of farmers into four types. Resource persons (extension officer, chairman of cooperative, well informed farmers) were interviewed to triangulate whether the typology represented all farmers (including the poorest and wealthiest) in the community.

A detailed farm characterization was carried out among a sub-selection of 16 households. Stratification was applied to farm type (four random farmers per type were selected), and to climbing bean cultivation: per farm type two farmers were selected who cultivated a relatively large area of climbing beans (sole cropping or climbing beans contributing > 30% in intercropping), and two farmers who cultivated no or a small area of climbing bean (intercropping with < 30% climbing bean).

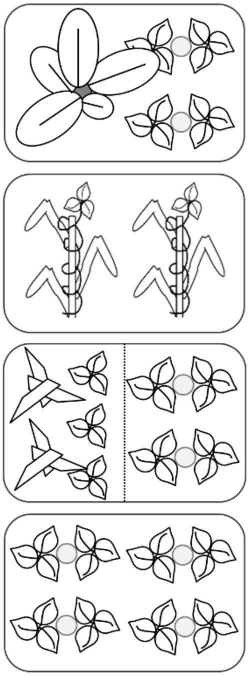
The detailed characterization consisted of four surveys, carried out during four visits. The first survey focused on the fields and crops on the farm. Households were asked to record yields for all their climbing bean fields. A cup and recording sheet were handed out to measure fresh bean consumption during the season, and sacks were handed out per field to store dry grains for later measurement. In the second survey, all cultivated fields of the farm were visited with questions on field history, topography and crop management. Fields were measured using a handheld GPS device, or manually if the field was too small. On climbing bean fields, measurements of stake density, stake length and number of plants per stake were taken on two quadrats of 2 x 2 m (one quadrat on smaller fields). Soil samples were taken from three to four fields per farm (composite samples at 0-20 cm depth) with the most common crops in the area, and from at least one climbing bean field if present. Collected soil samples were air-dried, sieved and ground, and analysed for pH (1:2.5 H_2O), organic carbon (Walkley & Black), total N (Kjeldahl), plant available-P (Mehlich III), Ca, Mg and K

(Mehlich III) at the National Agricultural Research Laboratories in Kawanda, Uganda. The third survey contained questions on household income and expenditure and opportunities and constraints for climbing bean cultivation. The fourth survey was conducted at the end of the cropping season (Season 2014A) to assess yields. The climbing bean yield, collected by the farmer and air-dried, was weighed. Fresh bean consumption was also recorded. For all other annual crops farmers were asked to estimate the yield per field. Maize was not yet harvested at the time of survey, so farmers were asked to estimate their 2013 maize yields on the same field. Annual banana yields were assessed by asking for typical weekly yields at the moment of survey, and months in the year in which these yields were larger or smaller than that. For a detailed description of the methods and results of the characterization, see Marinus (2015).

2.3 Baseline and four options for climbing bean cultivation

For all 16 farmers in the detailed characterization, we assessed the *ex-ante* impact of four options for climbing bean introduction or expansion (Fig. 5.1). First, farmers' current situation was established based on the data collected in the detailed characterization. The four options were compared with this baseline. In Option 1, we explored the effects of intercropping climbing beans in a banana/ coffee garden (inter). In Option 2, climbing beans would be planted as relay-crop in a field of maize + bush bean intercropping (relay). Bush beans are harvested first. Maize cobs are harvested fresh and stalks are left in the field to serve as stakes for the climbing beans. Option 3 served as comparison between maize + bush bean intercropping and climbing bean cultivation. It was assumed that 50% of a maize + bush bean field was replaced with climbing bean sole cropping (replace). Option 4 represented a sole crop of climbing bean, grown with wooden stakes (sole). The four options were conceived to compare the benefits and trade-offs of: common practices of farmers already growing climbing beans in the area (Options 1 (inter) and 2 (relay)); the cultivation of climbing beans versus maize and/or bush beans (Options 3 (replace) and 4 (sole)); the use of different staking methods (Options 2 (relay) and 4 (sole)). For each option, we considered two scenarios: a 'current management' scenario in which climbing bean yields were in line with current yields obtained in the detailed characterization, and a 'best management' scenario with improved climbing bean yields through fertilizer use and improved management practices, based on results from climbing bean trials (See 2.3.2 for more detail).

We assumed that each option was applied to all fields on the farm available for that option: in Option 1 (inter) climbing beans were grown on all current coffee and/or banana fields; in Option 2 (relay), 3 (replace) and 4 (sole) on all maize + bush bean intercropping fields. Option 1 (inter) could be applied by farmers in both seasons, and we therefore assumed that farmers would grow climbing beans in the first and the second season. Option 2 (relay) could only be applied in the second season, and Option 3 (replace) only in the first season. To compare Option 4 (sole) with Option 2 (relay) on the effects of different staking materials, we also assumed that Option 4 (sole) was applied only in the second season.



Option 1 (inter): climbing bean intercropping in banana/ coffee garden. Additive or replacement of bush bean in both the first and second season.

Option 2 (relay): relay cropping of climbing beans in a maize + bush bean field, whereby maize stalks serve as stakes. Additive or replacement of bush bean in the second season.

Option 3 (replace): climbing beans replace maize. Half of a maize + bush bean field is replaced with a sole crop of climbing bean in the first season.

Option 4 (sole): sole crop of climbing bean with wooden stakes. Climbing beans are additive or replace bush bean in the second season.

Fig. 5.1: Schematic representation and overview of four options for climbing bean cultivation in farming systems of the eastern highlands of Uganda considered in this study

2.3.1 Data and assumptions for baseline

The comparison between the baseline and the four options was based on food crops produced on the farm. Non-food crops (coffee) and livestock products were not included in the analysis. Crop yields were derived from the detailed characterization. In case of missing data, the average yield for that crop among all farmers was allocated to the field. Banana yields were reported as the estimated number of bunches harvested per month. Bunch weight was not measured; we took an average of 19 kg per bunch for all farms (Wairegi et al., 2009).

2.3.2 Data and assumptions for the four options

The information gathered in the detailed characterization was combined with a second data set with experimental data on climbing bean yields to explore the effects of the four options. These data were collected from the adaptation trials in which farmers received a package of seed of an improved climbing bean variety and fertilizer, together with information on best management practices to try out on their own field (more detail in Ronner et al., 2017). Data from yields on farmers' own climbing bean plots planted next to the trial plots were collected as well. This data set included a total of 235 farmers in Kapchorwa district in Seasons 2014B, 2015A and 2015B. The yields measured in the adaptation trials were used to calculate expected climbing bean yields for the four options.

We assumed that farmers' current yields per field would give an indication of the quality of the field and the management capacities of the farmer. The climbing bean yield that could be achieved on a particular field was therefore related to the yield of the current crops (bush bean or maize + bush bean) on that field as reported in the detailed characterization for the 'current management' scenario. In case of missing yield data, average climbing bean yields were used. Climbing bean yields per field for Option 1 (inter) were calculated as:

$$Current\ bush\ bean\ yield\ intercropping\ \times \left(\frac{Average\ climbing\ bean\ yield\ intercropping}{Average\ bush\ bean\ yield\ intercropping}\right)$$

And for Options 2 (relay), 3 (replace) and 4 (sole) as:

$$Average\ best\ sole\ climbing\ bean\ yield\ \times \left(\frac{Current\ maize + bush\ bean\ yield}{Average\ best\ maize + bush\ bean\ yield}\right)$$

Average climbing bean and bush bean yields in intercropping were based on the adaptation trials. The average best sole climbing bean yield was calculated as the 10% (n=23) largest climbing bean yields in the adaptation trials. The average best maize + bush bean yield was calculated as the 10% (n=3) largest maize + bush bean yields in the detailed characterization.

For the 'best management' scenario we calculated the average (best) climbing bean yields achieved only by farmers who used TSP or DAP fertilizer in the adaptation trials. In this best management scenario we assumed that all farmers would be able to obtain these average (best) yields, unrelated to their current (maize +) bush bean yield.

2.4 Farm level indicators

We assessed the effects of the four options for climbing bean cultivation on four farm-level indicators: food self-sufficiency, income, investment costs and labour requirements. Based on these indicators, we also calculated profit, income:cost ratios and returns to labour.

For food self-sufficiency, the yields of the crops produced on the farm were converted to kcal based on a food composition table for Uganda (Hotz et al., 2012). We considered average values for the combination of all crop varieties and most frequently used processing forms (e.g. excluding dried, raw products), resulting in an average of 114 kcal (per 100 g) for banana, 120 kcal for common bean (bush + climbing), 86 kcal for Irish potato and 244 kcal for maize. The kcal contents of all crops per farm were added and divided by the amount of kcal required by the household. We assumed that adults would need an average of 2250 kcal per day and children < 18 years 1850 kcal per day (FAO et al., 2001).

Prices of crops were asked from farmers in the detailed characterization. The average price per crop (UGX per kg of produce) was calculated over all farms, and multiplied by the production of each crop per farm. Income was converted to US$ according to the prevailing rate in 2014 (1 US$ = 2600 UGX). The income per farm was related to the poverty line (1.90 US$ per hh member per day), and converted to Purchasing Power Parity (PPP) for Uganda (multiplied with a factor 1,089, World Bank, 2015). The income earned from cropping per farm was then expressed as percentage of the income required per household. Note that this is gross income, costs were not deducted.

Prices and rates for seed and inputs (fertilizer, stakes) per crop were obtained from farmers in the detailed characterization and averaged over all farms to obtain investment costs for the current management scenario. For the best management scenario we assumed that in sole cropping, climbing bean seed was applied at a recommended rate of 50 kg ha^{-1}, stakes at density of 40,000 ha^{-1} and fertilizer at a rate of 15 kg P ha^{-1} (Kaizzi et al., 2012; Ronner et al., 2017). For the intercropping plots we assumed that farmers would use 75% of these rates. All rates were applied as an average across farms. We assumed that fertilizer was applied in the form of DAP, as this was the only available fertilizer blend containing P at the time of study. Labour was not included in the investment costs but treated separately. Investment costs were divided over the number of household members for better comparison with food self-sufficiency and income which were also related to household size.

A labour calendar was asked for the three most important crops per farm (for a representative field on the farm). Labour requirements for maize + bush bean intercropping fields were estimated together; all other crops separately. Labour requirements were reported per activity (land preparation, sowing, weeding, staking and harvest). These were added up to a total per crop (person days ha^{-1}) and multiplied by the estimated percentage ground cover of that crop to get a total requirement for all crops in the field. For the best management scenario, we assumed that fertilizer was applied per planting hole and would require 12 days ha^{-1} (Van Heemst et al., 1981). Additional labour required for staking was obtained by multiplying the current labour for staking with a factor representing the difference between the current average staking density and the recommended staking density. Total labour requirements per farm were divided by the labour available in the household, as for all household members it was known in which months of the year they worked on the farm. Labour productivity was multiplied by a factor 0.5 for household members < 16 years.

2.5 Ex-ante impact assessment tool for participatory analysis of options

In 2017, the effects of the four options on the farm-level indicators were discussed with a sub-sample of the 16 farmers from the detailed characterization in Chema sub-county. For this purpose, we constructed a simple spreadsheet model using the abovementioned data, assumptions and calculations of the farm-level indicators. This model allowed calculating food self-sufficiency, income, costs, profit and labour for each farm; and exploring the trade-offs associated with different options in terms of food self-sufficiency and income on the one hand, and costs and labour on the other. As the discussions took place three years after the detailed characterization, a first step was to update the model input with current household size, crops grown, field sizes and yield. The model output was translated into graphical representations of bags of grain, money (income and costs) and labour to ease the interpretation by farmers (Annex C, Fig. C1).

For the discussions, we selected two farmers per farm type (eight in total) with interesting outcomes, e.g. those who were (almost) food self-sufficient, had a high income from cropping, had few opportunities, etc. Only seven of these farmers could be retraced. In addition to the seven farmers, we selected eight farmers from Kapchesombe and Kaptanya sub-counties, where climbing beans were new for most farmers. These eight farmers had been part of a participatory wealth ranking in 2014, and we had a broad indication of their farming background and ability to invest in agriculture. We discussed the effects of the different options on the farm-level indicators with these 15 farmers individually. We first asked whether there had been major changes on their farm or in sources of income between 2014 and 2017, which confirmed that no adjustments in farm types were needed. Next, the model input was updated and one to three relevant options were discussed with each farmer. These options depended on whether the farmer already grew climbing beans, which fields the farmer had (maize + bush bean or banana/coffee fields), and farmers' own preferences for options. Indicators were discussed one by one, and farmers were asked to compare the baseline and the option per indicator. Next, farmers prioritized the indicators and mentioned constraints for the option. They also indicated which option they preferred. Finally, we discussed implications at farm level, in terms of the importance and contribution of different crops to the farm, diversification and risk spreading versus yield/ income maximization and other values of climbing beans such as their biomass production, rotational benefits and drought/ rainfall tolerance.

2.6 Key informant interviews

We interviewed seven additional farmers individually as examples of 'successful' climbing bean farmers. Most of these farmers grew climbing beans since the start of the climbing bean dissemination campaign, and were farmers who tried innovative staking methods, grew climbing beans in the dry season with irrigation, grew climbing beans on a large scale, etc. These interviews were held to explore whether these farmers continued to grow climbing beans and in what way, what role climbing beans currently played in their livelihood, if they marketed the beans collectively and so on.

Two focus group discussions with key informants were held to enrich our understanding of trends in climbing bean cultivation since the start of the dissemination campaign; the availability of seeds, inputs and output markets; prices of inputs and outputs in 2017; changes in demand or volumes traded and the role that climbing beans could play in farming systems. Informants participating in the discussion were team members of the dissemination project, community based facilitators, agro-input dealers, local buyers, successful climbing bean farmers and chairmen of cooperatives.

3. Results

3.1 Farm and field characteristics

3.1.1 Farm types

Four farm types were distinguished to describe the diversity of households in Chema sub-county (Table 5.1). Farm types (FT) 1 and 2 were the wealthiest households based on resource endowment, production orientation and sources of income; the high resource endowed (HRE) farm types. FT3 and FT4 were the medium (MRE) and low (LRE) resource endowed households. Farmers in FT2 (HRE) had the largest landholdings, and the sale of farm produce was their most important source of income (typically half of the produce was sold, and half was kept for home consumption). In terms of landholding and livestock ownership, FT1 (HRE) was comparable to FT2 (HRE) and FT3 (MRE). The main source of income of FT1 (HRE) however, was off-farm income from a salary (e.g. teacher, government worker, security guard), pension or remittances. FT1 and FT2 are therefore referred to as FT1 (HRE – off-farm) and FT2 (HRE – farm) respectively. FT4 (LRE) mostly depended on income from casual labour off-farm and had some income from selling small amounts of farm produce. FT3 (MRE) also sold farm produce and had additional income from small businesses (e.g. shop keeper, carpenter) or petty trade. Characteristics not used to develop the initial typology often also differed between the farm types: FT1 (HRE – off-farm) and FT2 (HRE – farm) hired labour most frequently, FT2 (HRE – farm) was the most food secure and had the eldest household heads. University education was only present among FT1 (HRE – off-farm). Another specific characteristic was the ownership of fields in the lowlands (around 1400 masl), in addition to the fields closer to the homestead in the highlands (around 1700 masl). Ownership of lowland fields was highest for FT2 (HRE – farm) and lowest for FT4 (LRE). Although these fields were further from the homestead (>1 hour walking), due to land scarcity this seemed the easiest option for farmers in Chema to expand their cultivated area. In comparison with the total population surveyed, FT3 (MRE) was the largest group of households (40%), followed by FT1 (HRE – off-farm) (25%), FT4 (LRE) (20%) and FT2 (HRE – farm) (15%). The poorest households of FT3 (MRE) and FT4 (LRE) together comprised about 65% of the total population.

3.1.2 Crop cultivation and field characteristics

The most commonly cultivated crops in Season 2014A were maize, bush bean, climbing bean, Irish potato, coffee and banana. Farmers judged maize and banana to be their most important crops, followed by bush bean, coffee and ‘beans’ in general. At the start of the study, climbing beans were therefore not considered of major importance to farmers.

Table 5.1: Farm types in Chema based on a rapid farm characterization survey (*n*=75). Characteristics marked with "*" were used to construct farm types. Other characteristics were analysed to assess additional differences between farm types. Values shown between brackets are minimum and maximum values.

	Characteristics	Farm type 1 (HRE – off-farm)	Farm type 2 (HRE – farm)	Farm type 3 (MRE)	Farm type 4 (LRE)
	n	18	12	30	14
Resource endowment	Cultivated land*	0.4-2 ha	1.2-3.6 ha	0.4-1.2 ha	<0.4 ha
	Type and number of livestock*	0-5 cows, 0-3 goats, 1-15 chickens	0-8 cows, 0-8 goats, 5-15 chickens	1-3 cows, 1-4 goats, 2-5 chickens	1 local cow[1] or 1 goat, 1-2 chickens
	Type of housing*	Iron sheet roofs, semi-permanent and permanent walls	Iron sheet roofs, semi-permanent walls	Iron sheet roofs, semi-permanent walls	Thatched or iron sheet roof, semi- permanent walls
	Valuable goods owned*	Cell phone, radio, motor bike or car	Cell phone, radio, sofa and plough	Cell phone, radio and/or sofa	Max. one cell phone or radio
	Households hiring labour during season	94%	83%	67%	53%
Household characteristics	Average age household head	44 (28-90)	50 (29-74)	43 (24-70)	39 (20-70)
	Education level household head	Most secondary, part primary and some university	Primary and secondary	Most secondary, part primary	Most primary, part secondary, some none
	Average months of food insecurity	2.4 (0-4)	1.1 (0-3)	2.0 (0-3)	2.3 (2-3)

	Characteristics	Farm type 1 (HRE – off-farm)	Farm type 2 (HRE – farm)	Farm type 3 (MRE)	Farm type 4 (LRE)
Production orientation, sources of income	Type of crops (season 2014A)	Banana, coffee, bush bean 33% has lowland fields	Banana, coffee, bush bean 75% has lowland fields	Banana, coffee, bush bean 47% has lowland fields	Banana, coffee, bush bean No lowland fields
	Production orientation*	Most home consumptio part sold	Half sold, half for home consumption	Most home consumption, part sold	Mostly for home consumption
	Most important source of income*	Off-farm income most important (>50%)	Farm produce most important, other source <30%	Farm produce most important, some other source of income (0-50%)	Casual labour and some farm produce

[1] *FT1 only owned local cattle breeds whereas other farm types sometimes also owned improved breeds.*

Despite this, 68% of the farmers (in the rapid characterization) indicated that they grew climbing beans, on 28% of fields. Only 7% of the farmers growing climbing beans grew them as sole crop; the majority intercropped climbing beans with coffee, banana or other crops. Climbing beans in intercropping usually comprised less than 30% ground cover.

Fields with climbing beans were smaller than average, both in sole and intercropping (Table 5.2). Fields with maize + bush bean were generally largest. These fields were also located at lower elevation, further away from the homestead. Climbing beans intercropped in banana/ coffee gardens were grown closest to the homestead, followed by coffee banana gardens with other or no intercrops, and sole climbing beans. These fields were all found around 1800 masl. Main soil fertility parameters did not differ among fields or farm types (Annex C, Table C1).

Table 5.2: Field size, elevation and distance to the homestead of fields with the most commonly cultivated crops in Chema

Main crop	*n*	Field size (ha)	Elevation (masl)	Distance to homestead (m)*
Climbing bean intercropping	6	0.10	1801	280
Climbing bean sole cropping	4	0.11	1807	540
Banana/ coffee	13	0.12	1819	340
Maize + bush bean**	16	0.40	1539	2580
Total/ average	39	0.30	1723	990
P-*values*		*< 0.001*	*< 0.001*	*< 0.001*

** As the crow flies*

*** Includes one field with Irish potato. Taken together as common rotation is maize and Irish potato on the same field.*

Common crop rotations were maize + bush bean intercropping in the first season, followed by sole bush bean in the second season (23% of fields). In the first season of the next year either maize + bush bean or Irish potato (on fields at higher elevation) were grown. A few farmers grew maize every year, but left their land fallow in the second season (9%). In banana/ coffee gardens, two consecutive seasons of bush bean were common (34% of fields). None of the farmers indicated that they grew climbing beans in the second season. Bush bean or fallow were the only options mentioned for the second season. The use of fertilizer (DAP, urea, CAN) was limited to fields with maize (with or without bush bean) or Irish potato. Only one farmer applied DAP specifically to bush bean. None of the farmers applied mineral fertilizers to climbing beans. Manure was only applied to banana/ coffee gardens.

3.2 Climbing bean yields, prices, investment costs and labour for the four options

3.2.1 Climbing bean yields

Crop yields that were used as a basis to calculate the different options under the current and best management scenario are given in Table 5.3. The climbing bean yields in intercropping represent different densities of climbing bean ground cover (30% climbing beans on average). For Option 2 (relay), we derived yields of climbing beans grown on maize stalks from a comparison of the measured yields of climbing beans on maize stalks and on wooden stakes in the adaptation trials. In these adaptation trials, the yields of climbing beans planted with wooden stakes was 1200 kg ha^{-1}, with maize stalks 890 kg ha^{-1}. The relative difference (890 kg ha^{-1}/ 1200 kg ha^{-1} = factor 0.65) was applied as a yield penalty for the use of maize stalks in Option 2 (relay), compared with the wooden stakes in Options 3 (replace) and 4 (sole).

3.2.2 Prices, investment costs and labour

Prices for climbing bean were comparable to bush bean: 0.61 versus 0.64 US\$ kg^{-1} in 2014. Prices for maize were about half of the price for beans with 0.30 US\$ kg^{-1}, and prices for Irish potato were smallest with 0.19 US\$ kg^{-1}. Banana had an average price of 3.50 US\$ per bunch.

Investment costs were only considered for the annual crops (not for banana). The information for Irish potato was insufficient to make a good comparison, so only climbing bean, bush bean and maize were compared (Table 5.4). Investment costs for climbing beans in the current management scenario consisted of seed and stakes. Different seeding and staking rates were used for sole and intercropped climbing bean fields. The larger seeding rate and smaller staking rate on the intercropped fields indicate that management of climbing beans on these fields was generally poorer than on sole cropped fields (larger numbers of plants per stake). In general, the seeding rate was much larger than the recommended rate of 50 kg seed ha^{-1} (often done to compensate poor emergence) and the number of stakes much smaller than the recommended 40,000 stakes ha^{-1}. The only investment cost considered for bush bean was seed. All farmers used hybrid maize seed, which is considerably more expensive than seed of bush or climbing beans. Fertilizer was used on half of all maize fields. All farmers applied DAP in combination with either urea or CAN. Prices of urea and CAN were comparable.

Farmers' estimated labour requirements for climbing bean were much larger than for maize + bush bean fields (Table 5.5). Not only staking and harvest were considered to require more labour, but also land preparation, sowing and weeding. Estimates differed considerably for crops grown on small and large fields, however, reflecting economies of scale. To simplify comparisons among crops, median labour requirements were allocated across all options, irrespective of field size.

Table 5.3: Crop yields (kg ha^{-1}) used for the calculation of four options for climbing bean cultivation under current and best management in the eastern highlands of Uganda

	Grain yield (kg ha^{-1})			Data source	Comment
	Option 1 (inter)	Option 2 (relay)	Option 3 (replace) & 4 (sole)		
Climbing bean (current management*)	815	3000 * 0.65	3000	Adaptation trials	Measured
Climbing bean (best management**)	1620	5000 * 0.65	5000	Adaptation trials	Measured
Bush bean	400	-	-	Adaptation trials	Farmer reported
Maize + bush bean	-	-	2570	Detailed characterization	Farmer reported

** Figures presented in table related to current yields on farmers' fields*

*** Figures presented in table applied across all fields, unrelated to current yields on that field*

Table 5.4: Inputs, rates and prices used for the calculation of investment costs for four options for climbing bean cultivation under current and best management in the eastern highlands of Uganda

Crop	Input	Unit	Rate (unit ha^{-1})	Price per unit (USD)
Climbing bean	Seed (sole cropping)	kg	75	0.69
(current management)	Seed (intercropping)	kg	100	0.69
	Stakes (sole cropping)*	stake	27,850	0.04
	Stakes (intercropping)*	stake	22,500	0.04
Climbing bean	Seed (sole cropping)	kg	50	0.69
(best management)	Seed (intercropping)	kg	38	0.69
	Stakes (sole cropping)*	stake	40,000	0.04
	Stakes (intercropping)*	stake	30,000	0.04
	Fertilizer (DAP)	kg	75	0.91
	Fertilizer (DAP)	kg	56	0.91
Bush bean	Seed	kg	80	0.67
Maize	Hybrid seed	kg	22	4.17
	Fertilizer (DAP + Urea/ CAN)	kg	143	1.75

** Stakes were generally used for four seasons, so total staking costs were divided by four.*

Table 5.5: Median labour requirements (person days ha^{-1}) for farm operations and total labour requirements per season per crop. LP = land preparation, SO = sowing, ST = staking, W1-4 = weeding 1-4, HA = harvest.

	n	LP	SO	ST	W1	W2	W3	W4	HA	Total
Climbing bean	11	129	70	122	83	71			122	596
Maize + bush bean	11	32	37		44	44			59	216
Bush bean	4	125	148		117	109			63	561
Maize	3	160	80		160	160			84	644
Banana	15				114	116	117	121		468
Irish potato	1	319	53		106	106			266	850

This median may underestimate labour costs on the generally smaller fields in Option 1 (inter), and overestimate them on the larger fields in the other options.

3.3 Effect of the four options on farm level indicators

3.3.1 Food self-sufficiency

In the baseline, three households of FT1 (HRE – off-farm) and FT4 (LRE) were not food self-sufficient (Fig. 5.2A).

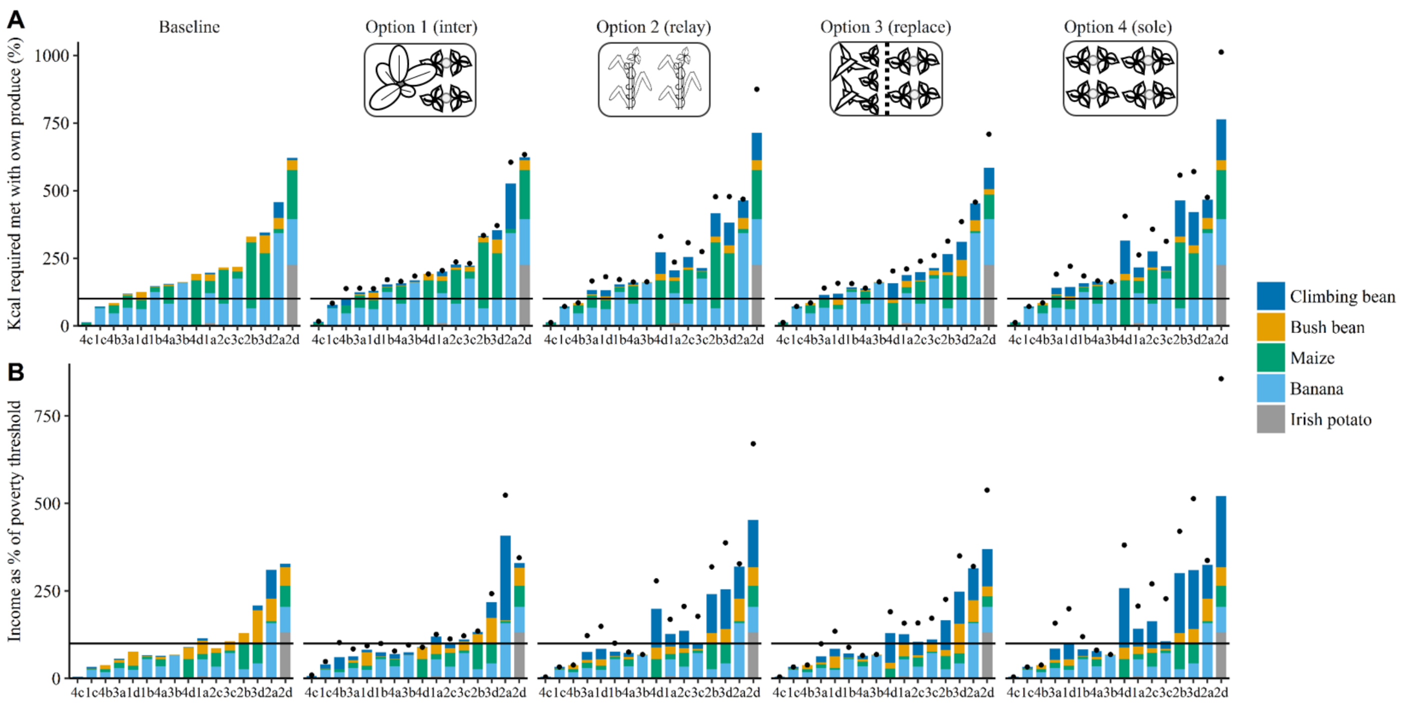


Fig. 5.2A&B: Effects of four options for climbing bean cultivation on food self-sufficiency (annual kcal required by household divided by kcal supplied by crops from farm (%)) (A) and annual income from crops as percentage of poverty threshold (1.90 USD in purchasing power parity per household member per day) (B) under current management. Black dots per option show effects under best management. Numbers on the x-axis represent Farm types 1 (HRE – off-farm), 2 (HRE – farm), 3 (MRE and 4 (LRE), letters a-d the four farms within the type. Farms in all graphs are ordered from least to most food self-sufficient in the baseline.

FT2 (HRE – farm) and FT3 (MRE) were generally most food self-sufficient. The crops that contributed most to food self-sufficiency were banana and maize; the contribution of climbing beans was small. Under current management, food self-sufficiency increased in all options, with the exception of Option 3 (replace). As maize yields more both in terms of kg of produce and calorific value, replacing 50% of the maize + bush bean field with climbing beans reduced food self-sufficiency. In Option 1 (inter) the increase in food self-sufficiency was modest, as banana/ coffee fields were generally small. Option 4 (sole) provided the largest increase in food self-sufficiency, because of the larger sizes of maize + bush bean fields and because of the 65% reduction in yields in Option 2 (relay) resulting from the use of maize stalks. Under best management, the increase in food self-sufficiency of Option 1 (inter) remained modest, but in the other options climbing beans gained a much larger share of the total produce. Food self-sufficiency also increased in this scenario for most farms in Option 3 (replace) compared with the baseline.

3.3.2 Income

The price differences between crops resulted in a different picture for income than for food self-sufficiency (Fig. 5.2B). Banana still contributed an important share of the total income, but bush and climbing beans were relatively more important than maize compared with food self-sufficiency. In the baseline, a few farms from FT2 (HRE – farm) and FT3 (MRE) had an income from cropping larger than the poverty threshold (NB: gross income; costs not deducted). With current management, income increased in all options. The increase in Option 3 (replace) resulted from the better price for climbing bean than for maize, which compensated for the loss in kg of produce. In Option 1 (inter), the increase in income was again modest with the exception of a few farms. These farms had a considerable share of their farm under banana/ coffee, and the better yields for climbing beans compared with bush beans caused a large increase. On average, the gross income obtained from climbing beans was 100 to 450 US$ per farm in options 1 (inter) and 4 (sole) respectively. From maize, this was about 340 US$. Income from coffee, the most important cash crop in the area, averaged 350 US$ per farm and off-farm activities contributed almost 1000 US$ (data not presented). Under best management, in Option 4 (sole) 11 out of the 16 farms could earn an income from farming larger than the poverty threshold. Also in the other three options, climbing beans gained an important share of the total farm income, up to half of the total income from cropping.

3.3.3 Investment costs

For the baseline, investment costs for maize were often about three times as high as investment costs for bush bean (Fig. 5.3A). Investment costs for climbing bean ranged from 4 to 55 US$ per household member, for bush bean from 2 to 30 US$. With Option 1 (inter) under current management, investment costs increased considerably, even though field sizes in intercropping were generally small.

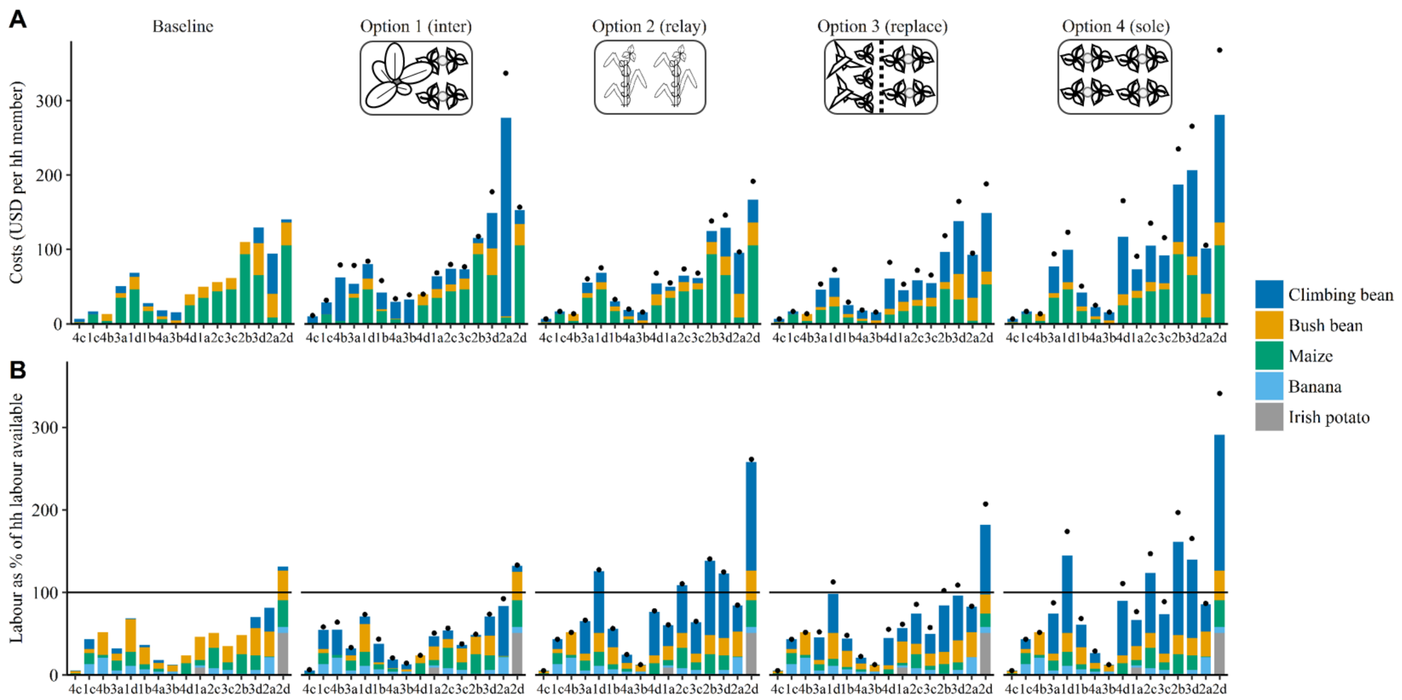


Fig. 5.3A&B: Effects of four options for climbing bean cultivation on annual investment costs for climbing bean, bush bean and maize (USD per household member) (A) and annual labour requirements per crop as % of total labour available in the household (B) under current management. Black dots per option show effects under best management. Numbers on the x-axis represent Farm types 1 (HRE – off-farm), 2 (HRE – farm), 3 (MRE) and 4 (LRE), letters a-d the four farms within the type. Farms in all graphs are ordered from least to most food self-sufficient in the baseline.

The contribution of staking to the total costs becomes visible through the comparison with Option 2 (relay). In this option, the additional investment in climbing bean remained relatively small and comparable to the total investment in bush bean. Option 3 (replace), where investment costs generally decreased, indicated that investment costs for the same piece of land were smaller for climbing bean than for maize. However, farmers who did not apply fertilizer on their maize had relatively small costs and increased their investment costs with climbing beans because of the cost of staking. The increase in investment costs was largest for Option 4 (sole), as field sizes were generally larger than for Option 1 (inter), and farmers would have to make a considerable investment in stakes compared with Option 2 (relay). The costs for climbing beans in Option 4 (sole) contributed up to half of the investment costs, and increased to up to 140 US$ per household member. Under best management, investment costs remained moderate for Option 2 (relay). With Option 3 (replace), costs were larger than in the baseline. In Option 4 (sole), costs for climbing beans rose to over 200 US$ per household member.

3.3.4 Labour

In the baseline, all but one of the farms had sufficient household labour to cover annual requirements (Fig. 5.3B). Maize and bush bean generally required the largest share of labour. For Option 1 (inter) under current management, the additional labour requirement for climbing beans was small and comparable with bush bean. With Option 2 (relay), the labour required for staking was deducted from the total, as stakes were already in the field. Nevertheless, climbing bean labour requirements increased to about 50% of the total labour because climbing beans were additive on most farms in this option. The labour demand for Option 3 (replace) was larger than in the baseline, which reflects the large difference in labour on maize + bush bean and climbing bean fields (Table 5.5). Labour demands for Option 4 (sole) were largest. With this option, five farms exceeded their annual household labour availability. These farms would have to hire labour to meet the additional demand. However, as labour requirements for climbing bean coincide with land preparation, sowing and weeding of maize and bush bean (Annex C, Table C2), many more households would have to hire labour during these seasonal labour peaks (which also shows from Table 5.1). Under best management, the increase in labour for Option 2 (relay) was barely noticeable, considering the modest additional labour for fertilizer application. The labour required for staking increased considerably in Options 3 (replace) and 4 (sole), and labour for climbing beans went up to a third of the total labour requirement on some farms.

3.3.5 Profit, income:cost ratio and returns to labour

The average income that could be obtained from one ha of climbing beans was larger than from one ha of (maize +) bush bean in all options under current and best management (Table 5.6).

Table 5.6: Average seasonal income, cost, profit (USD ha^{-1}), income:cost ratio and returns to labour (USD day^{-1}) for four options for climbing bean cultivation under current and best management, and comparison with (maize +) bush bean cultivation in the eastern highlands of Uganda

	Average income (USD ha^{-1})	Average cost (USD ha^{-1})	Profit (USD ha^{-1})	Income:cost ratio	Returns to labour (USD day^{-1})
Baseline: bush bean intercropping	*279*	*53*	*226*	*5.2*	*0.5*
Option 1 (inter) – current	558	267	291	2.1	0.9
Option 1 (inter) – best	988	342	646	2.9	1.7
Baseline: bush bean sole cropping	*458*	*53*	*404*	*8.6*	*2.1*
Option 2 (relay) – current	868	52	815	16.6	1.8
Option 2 (relay) – best	1981	103	1878	19.3	4.1
Baseline: maize + bush bean	*888*	*278*	*610*	*3.2*	*4.1*
Option 3 (replace) – current	1300	321	979	4.1	3.2
Option 3 (replace) – best	2157	400	1757	5.4	5.3
Baseline: bush bean sole cropping	*458*	*53*	*404*	*8.6*	*2.1*
Option 4 (sole) – current	1336	282	1055	4.8	2.2
Option 4 (sole) – best	3050	457	2593	6.7	5.1

The average costs for climbing beans were generally also larger, however, meaning that the benefits from climbing beans can only be realized when farmers are able to make the necessary investment. If farmers could afford the investment, all options resulted in a larger profit than (maize +) bush bean cultivation. The income:cost ratios for climbing beans were, however, not always more favourable than for (maize +) bush bean – see Option 1 (inter) and Option 4 (sole). This is especially the result of the small investment costs for bush bean, consisting of seed only. Returns to labour were larger for climbing bean cultivation than for (maize +) bush bean in Option 1 (inter) and Option 4 (sole), but smaller for Option 2 (relay) and especially Option 3 (replace) under current management. Maize + bush bean cultivation had more favourable returns to labour than any of the climbing bean options under current management, which could explain its popularity. With climbing beans under best management, returns to labour were comparable or larger than maize + bush bean for all options except Option 1 (inter).

3.4 Opportunities and trade-offs: which farmers benefit most?

The quantitative analysis of the four options showed that climbing bean cultivation generally improved food self-sufficiency, income and profit, but often at the expense of larger investment costs and always with a larger labour demand (Fig. 5.4). An exception was Option 3 (replace): food self-sufficiency decreased, but income increased. Investment costs in this option were only larger for farmers who did not use fertilizer on their maize; their investment costs for maize + bush bean were relatively small and increased with costs required for climbing bean staking. In Option 2 (relay), investment costs only increased for farmers for whom climbing beans were additive. Farmers who would replace bush beans had smaller costs, because of the smaller seeding rate for climbing bean and comparable seed prices.

For FT4 (LRE), not all options were applicable: three out of four farmers had no banana/ coffee or maize + bush bean fields. This is the result of their small farm sizes and number of fields. The opportunities for the integration of climbing beans on small farms were therefore limited, unless climbing beans replace a different crop. Despite this, some farmers of FT4 (LRE) were among the four farms with the largest increases in food self-sufficiency, income and profit. The other farms with large increases were mostly in FT2 (HRE – farm), because of the large farm sizes among this group. Yet, this also resulted in the greatest increase in investment costs and labour for FT2 (HRE – farm). The picture for FT3 (MRE) was more diverse: some farmers had increasing, some decreasing costs with Options 2 (relay) and 3 (replace). Farmers of FT1 (HRE – off-farm) generally already cultivated bush beans in the second season and did not use fertilizer on their maize, so had a decrease in costs in Option 2 (relay) and 3 (replace). For FT1 (HRE – off-farm), climbing bean cultivation therefore provided the least trade-offs.

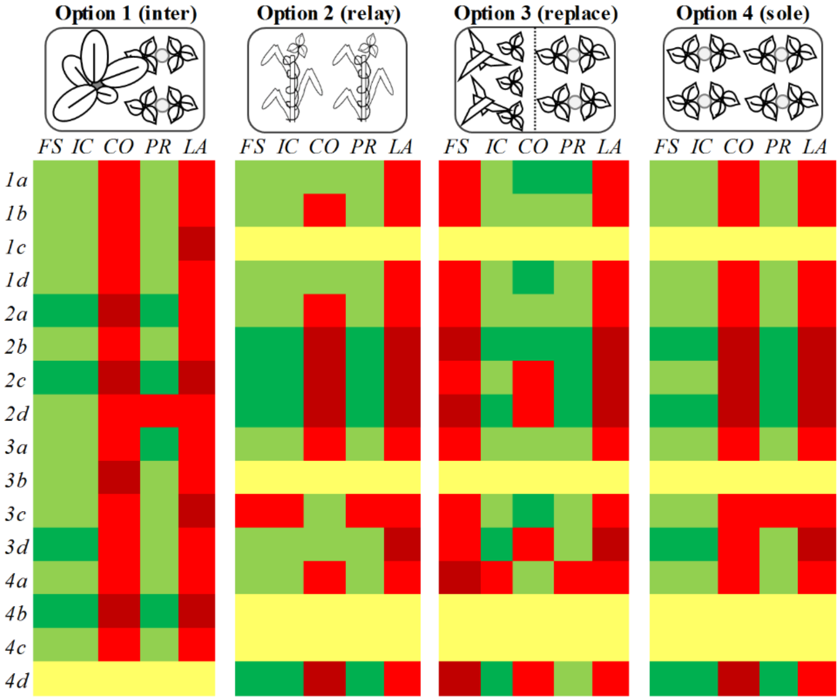


Fig. 5.4: Positive (green) and negative (red) effects of four options for climbing bean cultivation on food self-sufficiency (FS), income (IC), costs (CO), profit (PR) and labour (LA) at farm level. The four farms with the largest absolute advantage (dark green) and disadvantage (dark red) are highlighted. Yellow = no change. Numbers on the left represent Farm types 1 (HRE – off-farm), 2 (HRE – farm), 3 (MRE) and 4 (LRE), letters a-d the four farms within the type.

3.5 Farmers' priorities, constraints and decision-making

During the follow-up visits to discuss the four options with farmers in season 2017A, seven out of the 15 farmers that were interviewed still grew climbing beans, most of them from FT1 (HRE – off-farm), FT2 (HRE – farm) and FT3 (MRE). Option 1 (inter) was the most popular in practice: six out of the seven farmers grew climbing beans intercropped with banana/ coffee. All seven grew climbing beans on a relatively small piece of land. They indicated that both the availability of seed and stakes limited the area they could plant. In addition, farmers often mention frequent monitoring (staking, weeding, spraying), which makes cultivation close to the homestead attractive.

The use of maize stalks as staking material in Option 2 (relay) was preferred by five out of the 12 farmers (40%) with whom this option was discussed. Most of these farmers were from FT3 (MRE) and FT4 (LRE) and indicated that they knew wooden stakes would give a better yield, but could not afford to buy them. Option 2 (relay) was considered as a good start for climbing bean cultivation, as the use of wooden stakes could be expanded in subsequent seasons. The 60% farmers who preferred (and could afford) wooden stakes mostly mentioned the better yield and profit from wooden stakes, but some farmers also mentioned practical constraints such as destruction of maize stalks by termites, the location of the maize field in the plains (too hot and dry for the cultivation of climbing bean in the second season), and the fact that in the common rotation of maize, beans and Irish potatoes, maize would not be available every year.

Based on the quantitative analysis, we assumed that the decrease in food self-sufficiency in Option 3 (replace) would make this option less attractive for farmers who produced for home consumption (FT4 LRE), but interesting for market oriented farmers (FT2 HRE – farm). All ten farmers from different farm types with whom Option 3 (replace) was discussed, however, were interested in replacing their maize because of the better income from climbing bean. The reduction in food self-sufficiency did not matter to most: they were willing to buy maize. Most farmers did not produce enough maize for the whole year, or indicated that they sold their maize anyway because they did not have appropriate storage facilities. In addition, cash crops were considered of great importance to provide income for school fees. An advantage of climbing beans was therefore also that climbing beans can be grown (and provide income) twice a year, in contrast to maize or coffee. The additional labour demand and costs for staking were considered to be compensated by the larger profit (although Table 5.6 shows that for labour, this may not be the case).

Also in Option 4 (sole), farmers of all types pointed out that climbing beans would give a better yield, income and profit than bush bean, and that the additional costs and labour were worth the investment. However, two farmers who grew climbing beans on a large area (e.g. farmer 2a grew about 0.5 ha of sole climbing beans) during the detailed characterization indicated that they had not grown such large areas again, as the market prices for climbing beans were not good and they struggled to sell the beans. Interestingly, farmers indicated that the market demand for climbing beans had increased considerably in 2017 compared with 2014, which resulted in a much better price for climbing bean (0.63 US$ kg^{-1}) than bush bean (0.15 US$ kg^{-1}) and maize (0.17 US$ kg^{-1}). The grain (seed type) of the climbing bean varieties had gained local popularity (people first had to get used to them), and demand from Kampala also increased. Many farmers therefore indicated to be interested in an expansion of climbing bean production, replacing bush bean in the second season. The main constraint was a lack of seed. Only a few farmers still had small quantities of seed of the varieties distributed during the dissemination campaign, and people did not know where to get additional seed from. A better link to cooperatives focussing on climbing bean production was just established in 2017 and should help to address this problem. As Option 4 (sole) comprised climbing bean cultivation on a large scale (0.25 to 0.5 ha), farmers mentioned the need for stakes as disadvantage. Next to the money required to buy stakes, some farmers of

FT1 (HRE – off-farm) and FT2 (HRE – farm) also talked of poor physical availability of stakes. The option of using strings of sisal or nylon was considered of interest by these wealthier farmers for the cultivation of climbing beans on larger fields.

Next to better income and profit, other perceived advantages of climbing beans were their taste, cooking time, biomass production (leaves were often used as vegetables) and soil fertility benefits. Most farmers were aware of these benefits, but did not grow climbing beans for this purpose. Despite these advantages, all farmers mentioned that they would still prefer to grow a variety of crops ‘because that is what we eat’. They felt that it is better to grow your own food instead of buying everything. In addition, the majority of farmers would not want to replace all of their bush bean with climbing bean because bush beans are early maturing, providing food during the hunger period in the middle of the growing season. Some also preferred the taste of bush bean varieties. Farmers did not perceive the larger investment costs for climbing bean than bush bean to be a risk. They pointed out that stakes – the largest share of the additional investment – can be re-used, so even with a harvest failure the loss would not be much more than for bush bean.

4. Discussion

4.1 How do climbing beans fit in farming systems in the eastern highlands of Uganda?

Option 1 (inter) was the most common current cultivation method for climbing beans in the eastern highlands of Uganda. Intercropping is a common practice in land constrained areas to optimize production on small pieces of land (Willey, 1990; Lithourgidis et al., 2011). In combination with a lack of access to seed and capital required for staking this explains why climbing beans are grown on a small scale in home gardens. The lack of access to seed was especially problematic in Kapchesombe and Kaptanya sub-counties, where climbing beans were newest. Seed of climbing bean varieties was introduced through the dissemination campaign, but harvest failures and problems in storage (bruchid beetles) reduced the quantities of seed available (cf. Sperling and Loevinsohn, 1993; David et al., 2002). The better market prices for climbing beans in 2017 compared with 2014 enhanced farmers’ interest in climbing beans, and with increasing production volumes more seed would be available in the system, facilitating informal seed sharing. Reducing damage of seed in stores through the use of multi-layered grain storage bags could also improve the availability of seed (Murdock and Baoua, 2014).

The lack of stakes is a constraint frequently heard for climbing bean cultivation (Musoni et al., 2014; Ruganzu et al., 2014), and particularly in eastern Uganda (Ronner et al., 2017). Farmers commented, however, that if climbing beans give a good profit they are willing to invest in them. With improved marketing opportunities this constraint may therefore diminish, as seen in southwestern Uganda and Rwanda for instance (Sperling and Muyaneza, 1995). Moreover, despite attempts to introduce alternative staking materials (Musoni et al., 2014; Ronner et al., 2017), wooden stakes seem to be the easiest and least labour intensive method leading to the largest yields. The only alternative staking material currently used by a reasonable number of farmers is maize stalks. Some farmers described the maize stalks of Option 2 (relay) as a last resort option for poorer farmers, because costs are small but climbing bean yields are often reduced as well. Furthermore, with a hybrid maize variety and the use of fertilizer – particularly potassium (Melis and Farina, 1984; Li et al., 2012) – the maize could be strong enough to avoid lodging and minimize yield losses. Most farmers in the eastern highlands already use hybrids and fertilizer (although DAP and urea/ CAN do not contain potassium), and the free source of staking material could be an additional incentive for adequate investments in fertilizer.

Farmers of all types were interested in Option 3 (replace) because of the relative improvement in prices for climbing bean compared with bush bean and maize. This finding shows how adoption and crop choices greatly depend on market opportunities (Udoh and Kormawa, 2009; Hockett and Richardson, 2016; Ortega et al., 2016). The decrease in maize yield and food self-sufficiency with this option was not considered problematic, which is in contrast to farmers' preference for maize over legumes, and food self-sufficiency versus income in other studies (Leonardo et al., 2015; Ortega et al., 2016). The preference for income can be explained by access to legume grain markets (relatively good in eastern Uganda), and the value that farmers in this study attached to cash income to pay for school fees and to the poor storage facilities that forced people to sell maize. At a larger scale, the reduction in food self-sufficiency could mean that maize would have to be bought from other regions; an implication that was not discussed. It should also be noted, however, that a rotation of maize with climbing bean would enhance yields compared with continuous maize. After a legume, cereal yields in Africa were found to increase with an average of 0.49 t ha^{-1} compared with cereal yields after a cereal (Franke et al., 2017). If this average is applied across the farms in this study, the 50% loss in area of maize is largely compensated in the subsequent season because of the additional maize harvest.

Option 4 (sole) showed the potential contribution of climbing beans to food self-sufficiency and income when grown as sole crop on relatively large fields. With the aforementioned increase in demand for climbing beans and good market prices, all farmers commented that this could be an attractive option. However, as the option would also require the largest increase in investment costs and labour, it is questionable to what extent farmers (especially of FT3 (MRE) and FT4 (LRE)) can really afford this. In the discussions, farmers generally stated that they would be able to make these investments as long as the profit was good. Numerous studies have shown, however, that a lack of access to capital and labour are important constraints for adoption of agricultural innovations (Feder and Umali, 1993; Doss, 2006; Farrow et al., 2016). This implies that farmers may be ambitious but face constraints along the way and compromise on management, or that farmers' preferences and 'willingness to invest' are not necessarily good indicators for adoption (cf. Pircher et al., 2013; Waldman et al., 2014).

4.2 Putting food self-sufficiency and profit in context

In our assessment of food self-sufficiency we assumed that households would first use the produce from the crops on their farm for home consumption, and only then sell any surplus. This resulted in all but three households (80%) being food self-sufficient in the baseline. Table 5.1 shows that this assumption is not true, and farmers also indicated that they sold crops due to urgent cash needs or because of storage problems. We observed that 80% of the farms were food self-sufficient, a much larger proportion than found in other studies in Uganda (Wichern et al., in press) or western Kenya (Tittonell et al., 2009). The former study deducted crop sales from total food production, however, which we did not. Moreover, considering the fertile soils and two cropping seasons per year in Kapchorwa, food self-sufficiency can also be expected to be larger than average in Uganda. The farms in western Kenya studied by Tittonell et al. (2009) were of similar sizes, but produced maize and bush bean as staple crops. In our study, these crops contributed relatively little to food self-sufficiency compared with banana.

The average annual profit from climbing bean cultivation ranged from about 290 US$ per ha in Option 1 (inter) to 1050 US$ per ha in Option 4 (sole) under current management. These figures are around the average profit of agricultural innovations of 558 US$ per ha per season found by Harris and Orr (2014). The latter study included costs for labour, however. If we value labour costs in this study (casual labour equated to 1.9 US$ per day in 2014), both climbing bean and bush bean cultivation would result in a loss (only maize + bush bean cultivation would have a profit of 200 US$ per ha). Compared with other studies (Van Heemst et al., 1981; Franke et al., 2006), the labour requirements in our study seem to be severely overestimated (already by a factor 2 for maize + bush bean cultivation), probably because of the small field sizes. If we assume that labour requirements for climbing beans are roughly 1.5 times the average for maize in Franke et al. (2006) and Van Heemst et al. (1981) – 162 days per ha – profitability would range from 60 to 750 US$ per ha in Options 1 (inter) and 4 (sole) with labour costs included.

In the best management scenario, the average profit of ranged from 650 to 2590 US$, far above the 558 US$ per ha per season reported by Harris and Orr (2014). Although some farmers in the area indeed achieved yields of 5 t ha^{-1} in the adaptation trials, such yields require capital investments in fertilizer (which was provided in the adaptation trials) and stakes, and labour investments in timely management operations. Considering the generally small yields of other crops, farmers are constrained in capital and labour and will probably choose for an optimal allocation of resources over all these crops (and off-farm activities) rather than maximum investments in one crop (Barrett et al., 2001; Collinson, 2001). Thus this scenario may be unrealistic.

4.3 Added value of multi-criteria, farm level and participatory *ex-ante* impact assessment

Our *ex-ante* assessment of the impact of four options for climbing bean cultivation on multiple criteria clearly demonstrated the trade-offs associated with a change in farming system (Tittonell et al., 2007; Groot et al., 2012). If we compare climbing bean with bush bean based solely on yield, most would agree that climbing beans are a better option. However, relatively large additional investments (up to half of the total investment or labour in farming) need to be made before such benefits can be realized. Given irregular patterns of production and income, people often face major challenges in matching income to be accrued in future with current investment needs in inputs or labour (Dorward et al., 2009).

The identification of such trade-offs also shows the relevance of an analysis at farm level. Even though a technology may be positive at the field level, the required resources may not be available at the farm level. For instance, farmers would have to switch from relying on household labour to spending money on hired labour, or prefer to spend their money on more profitable activities. The comparison of income from climbing beans in relation to other sources of income (coffee, off-farm income) therefore also gave an impression of the relative importance of climbing beans in the total household income. In addition, the introduction of climbing beans would lead to the substitution of another crop on some farms. Even when the economic analysis showed that climbing beans were more profitable than maize or bush beans, farmers valued a diversity of crops for different purposes (Ondurua and Du Preezb, 2007; Dorward et al., 2009; Groot et al., 2012).

The latter priority also surfaced during the discussions with farmers. Based on the quantitative analysis, Option 4 (sole) was the option with the largest yields and profit. Yet, farmers had different arguments that led to different choices such as the preference for intercropping or the use of maize stalks. Other insights from discussions with farmers were the importance of income versus food self-sufficiency, and the positive feedback loop of increasing demand, increasing market prices and increasing interest in climbing bean cultivation. The combination of a quantitative exploration of impacts at farm level with qualitative feedback from farmers and other informants contributed to a better understanding of the actual benefits, constraints and potential adoption of technologies.

Finally, the use of farm types was useful to describe the diversity of farmers in Chema sub-county and to show how the effects of the four options differed between farm types. It allowed us to recognize the limited options available by the poorer farmers of FT4 (LRE) with the smallest farm sizes, and the accrual of benefits to farmers from FT2 (HRE – farm) with larger farms who derive most of their income from farming. Although farmers from FT4 (LRE) were also among the four farmers with the largest absolute benefits (Fig. 5.4), their limited resources will probably not allow them to make the necessary investments (Tittonell et al., 2007; Langyintuo and Mungoma, 2008). The latter was also reflected in the preference for Option 2 (relay) among FT3 (MRE) and FT4 (LRE). Wealthier farmers of FT2 (HRE – farm) could, and considering their dependence on farm income they probably will, re-invest the additional income in the farm, which in turn leads to increased production (Govereh and Jayne, 2003; Wichern et al., in press). However, our results also showed that the effects differed within the farm types. The ranking of farms according to food self-sufficiency indicated that FT4 (LRE), followed by FT1 (HRE – off-farm), were the least food self-sufficient, but with some exceptions. For the other indicators, the ranking was different, and there was no clear pattern in the effects for the different farm types. Recognizing diversity among smallholders is important and farm types can be useful to describe and categorize this diversity in terms of wealth and farming strategies (Bidogeza et al., 2009; Franke et al., 2014). Our study showed, however, that the effects of agricultural innovations cannot be predicted based on farm type, as effects varied both within and between farm types.

5. Conclusion

The *ex-ante*, multi-criteria exploration of climbing bean options showed that climbing beans generally improve food self-sufficiency and income, but often require increased investment and always demand more labour. The small farm sizes of the poorest households (FT4 LRE) resulted in fewer options for the inclusion of climbing beans than for larger farms. Moreover, poorer farmers may be unable to make the necessary investments in climbing bean cultivation. The combination of quantitative and qualitative information improved our understanding of farmers' decision-making, showing that farmers prioritized income over food self-sufficiency and that cash constraints were more important than labour constraints for climbing bean cultivation. The recent increase in market prices for climbing bean in the eastern highlands resulted in growing interest in their cultivation, but a lack of seed, next to a lack of stakes, is currently limiting climbing bean cultivation. Strengthening of farmer cooperatives to ensure large enough volumes of climbing bean seed and improved storage of seed are essential next steps to enhance climbing bean cultivation in the area.

Acknowledgements

We thank the Bill & Melinda Gates Foundation for partnering in this research through a grant to Wageningen University to support the project N2Africa: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (www.N2Africa.org). We also thank the farmers, extension officers, translators and the N2Africa-Uganda team for their cooperation in data collection.

Chapter 6

General discussion

6.1 General findings

The overall aim of this thesis was to identify niches for sustainable intensification of agriculture through legumes for different types of smallholder farmers in sub-Saharan Africa. A summary of the main findings is presented in Fig. 6.1. In Chapter 2 we demonstrated that averages of on-farm performance of technologies are of little value to estimate the benefits of a technology for individual farmers because of the strong variability in yield and responses to treatments. We were able to explain about half of the observed variability based on variables such as plant establishment, soil texture and fertility, rainfall and farm size. Yet, the potential to use this information to predict the performance of technologies or to target technologies to a new group of farmers remained limited. The application of a co-design process in Chapter 3 showed that farmers use a wider range of criteria for the evaluation of legume technologies beyond yield. A co-design process with farmers, researchers and other stakeholders resulted in a basket of options for climbing bean cultivation in Uganda which included alternative options for farmers with different production objectives, resource constraints and in different agro-ecologies. The options developed could be used across the East-African highlands. Chapter 4 explained farmers' use and adaptation of options developed through the co-design process. The large majority of farmers did not use the combination of practices that would lead to the largest yield – the 'researcher best-bet' technology – but adapted this technology. We observed variability in farmers' use of practices as well as in the performance of legume technologies on farmers' fields. Some relationships with explanatory variables were found, but inconsistencies in use of practices between years complicated the delineation of clear recommendations domains related to farm types. The inconsistencies also emphasize the need to consider the adoption of complex technologies as a dynamic process rather than a simple, binary variable that can be measured at one point in time. In Chapter 5, we explored the farm-level effects of the cultivation of climbing beans in the eastern highlands of Uganda (where climbing beans were new to most farmers), and concluded that although climbing beans improved food self-sufficiency and income, they often required increased investment and always demanded more labour than current farm configurations. Combined with a discussion with farmers, these findings improved our understanding of farm-level decision-making, showing that farmers prioritized income over food self-sufficiency and that cash constraints were more important than labour constraints for climbing bean cultivation.

The overall hypothesis was that it would be possible to recommend specific options for legume cultivation for different types of farmers, with differences between farmers mainly relating to agro-ecological and socio-economic variables. Throughout the research, however, we were confronted with variability (in yields, farmer preferences, and use and impact of the legume options), and inconsistencies in explanatory relationships which complicated the formulation of recommendations about the suitability of technologies for different types of farmers. Yet, among this complexity, what general lessons can we distil?

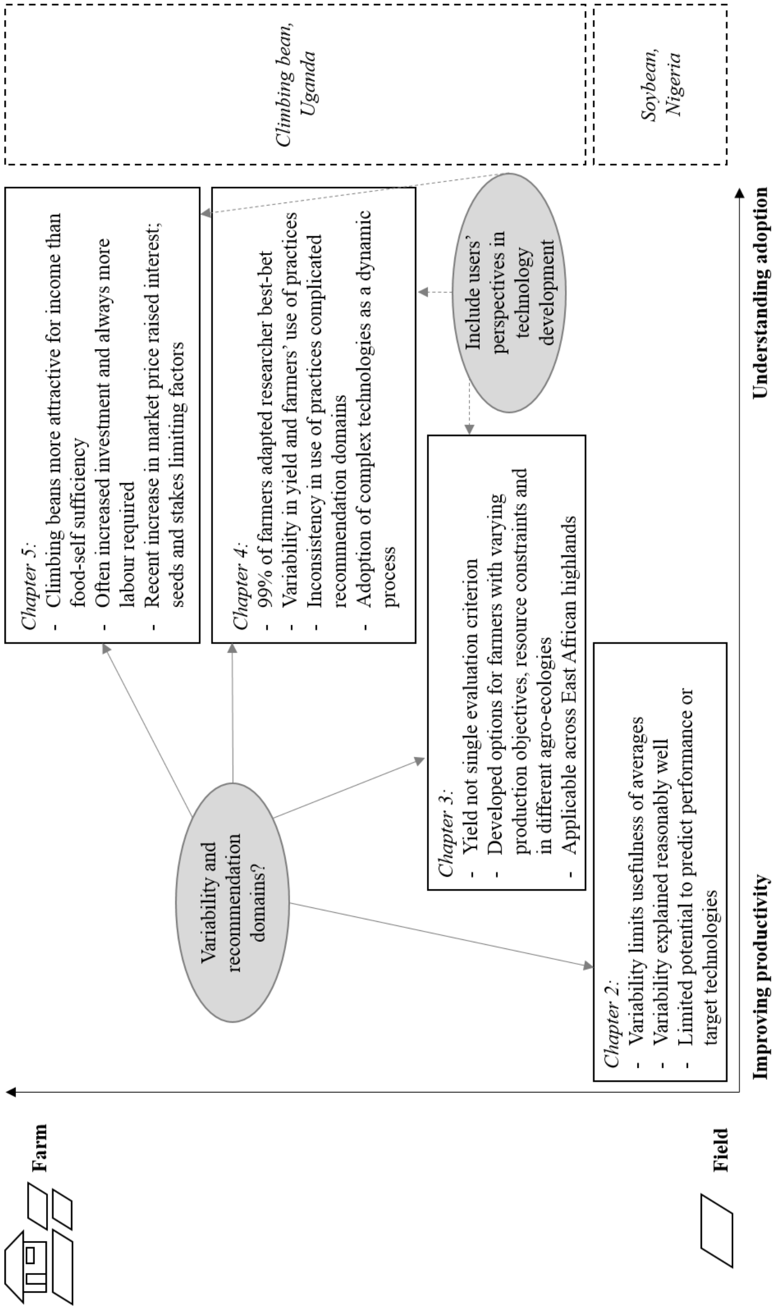


Fig. 6.1: Summary of thesis findings (black boxes) and cross-cutting themes (grey ovals)

In this discussion I first assess to what extent this thesis contributed to an improved understanding of the variability in legume yields and the use of practices. In a second section, I review the implications of the observed variability on the potential to derive relevant recommendations about the suitability of technologies for different types of farmers. Third, I discuss to what extent the co-design process has contributed to enhanced adoption of technologies. Next, I reflect on which aspects of the approaches used in this study could be integrated in large-scale dissemination projects, to better account for the needs of users of technologies within such projects. Finally, I discuss limitations of my study and present a way forward for improving productivity and adoption of legume technologies.

6.2 Understanding variability in legume yields and use of practices

In both Chapter 2 and Chapter 4 we diagnosed a strong variability in legume yields and response to inputs on farmers' fields. This variability is also found in other studies (Bielders and Gérard, 2014; Franke et al., 2016; Van Vugt et al., 2017), and has implications for the benefits and risks associated with technologies (Sileshi et al., 2010; Vanlauwe et al., 2016). This thesis contributed to the increasing recognition that the presentation of mere averages of yields and responses is not enough, and that measures of variability are needed, such as the frequency and distribution of responses and economic benefits.

Understanding the causes of variability could lead to the identification of niches in which a technology performs well and recommendations for targeting of technologies. In Chapters 2, 3 and 4 the largest differences in yield were found between regions. In Chapters 2 and 4 planting date was also an important factor. Together with some other variables such as plant establishment and soil fertility we were able to explain about half of the observed variability in Chapter 2. This percentage was comparable to findings of Bielders and Gérard (2014) and Falconnier et al. (2016), and could lead to some basic recommendations. However, much of the variability still remained unexplained. Also Franke et al. (2016) and Van Vugt et al. (2017), working with similar data sets, commented that many variables were confounded and that a true understanding of variability remains difficult. Similarly, in Chapter 4, we aimed to explain the variability in use of practices on farmers' fields. In this chapter, we had even more difficulty finding consistent relationships with household, plot or agro-ecological factors.

Our findings of poor cross-validation between seasons (Chapter 2) and the inconsistency in use of practices (Chapter 4) shed important light on our limited ability to understand variability. If farmers with the same characteristics use different management practices from year to year, their yield is also likely to differ from year to year. Such management factors are important determinants of yield next to environmental conditions (Tittonell et al., 2008). As management decisions were found to vary with changes in market conditions (Chapter 5), weather circumstances, pest and disease pressure and timely access to resources (Dorward et al., 2009; Misiko and Tittonell, 2011; Hockett and Richardson, 2016), their link with static farm types may be difficult to establish.

6.3 Implications of variability for recommendation domains

The poor predictability of yield and inconsistency in use of practices has implications for the identification of recommendations for targeting of technologies: even if we are able to explain variability in a certain year and derive recommendations from this, the recommendations may not hold in the next year. In Chapters 3 and 4 we aimed to identify the factors determining the suitability of technologies for different types of farmers. In the study design, we loosely followed the approach outlined by Farrow et al. (2016) in which different practices are tested and evaluated in different contexts. We selected the two regions in the eastern and southwestern highlands of Uganda based on expected differences in agro-ecology, market access and population density. Within these regions, we stratified households based on their socio-economic background (including resource endowment and production orientation) and gender (Fig. 6.2).

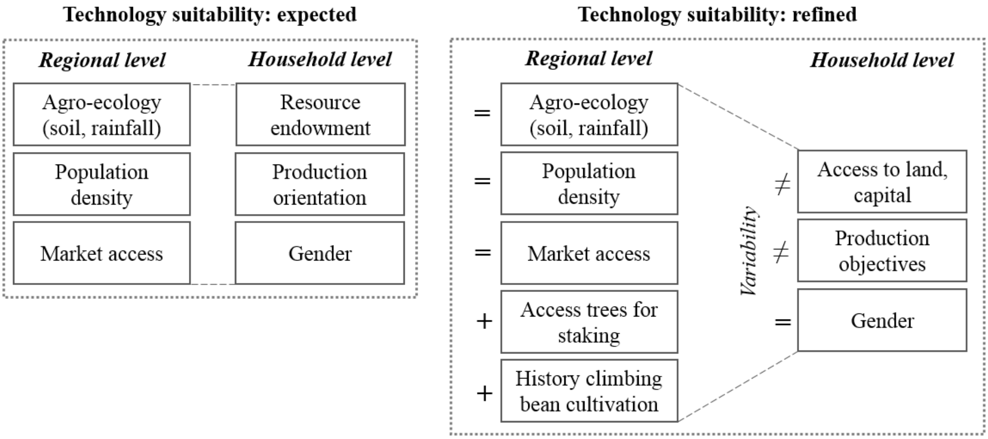


Fig. 6.2: Variables at regional and household level that determine the suitability of climbing bean technologies in the East-Africa highlands as expected during the design of the study and refined as a result of the study (Chapters 3 and 4). Variables remained the same (=), were added (+) or refined (≠).

Chapters 3 and 4 confirmed that regional differences played an important role in the evaluation and use of practices. Differences in soil fertility indicated that in the southwest the use of P-fertilizer was needed more, but virtually absent in practice due to the poorer market access and availability of inputs. The larger population pressure in the southwest increased the need for intensification which may have contributed to the popularity of climbing beans in this area. Compared with the initial design, two additional distinguishing factors at the regional level were identified: the access to trees for staking and the history of climbing bean cultivation (Fig. 6.2). The access to trees for staking may be a predictor of the likelihood of adoption of climbing beans, and can be used to determine if alternative staking materials are worth exploring (Sperling and Muyaneza, 1995; Musoni et al., 2014). The history of climbing bean cultivation (i.e. were farmers already introduced to climbing beans before) largely determines the types of interventions and research that are needed: should attention be paid to how to grow climbing beans, to what extent do climbing beans fit in the existing farming system (Chapter 5) and do seed systems need to be set up (Sperling and Loevinsohn, 1993; David et al., 2002); or should interventions mainly focus on improving the existing system (e.g. in terms of agronomic management or collective marketing)?

At the household level, the only characteristic that played an explanatory role in all chapters (including Chapter 2) was farm size. Farm size is a frequently mentioned factor explaining (benefits of) adoption (Harris and Orr, 2014; Farrow et al., 2016). Small farm sizes resulted in intercropping and in limited opportunities to include climbing beans on the farm. Other household characteristics important for the suitability of technology options were related to resource endowment and access to capital (cf. Marenya and Barrett, 2007; Franke et al., 2016; Tadesse et al., 2017), and influenced the evaluation of inputs and staking methods as well as climbing bean cultivation: poorer households cultivated climbing beans more often, but used fewer of the improved practices. The role of labour was less important than expected (Snapp et al., 2002a; Mugwe et al., 2009; Vandeplas et al., 2010), and when important not distinctive between households. Production objectives (not only production orientation, cf. Fig. 3.5) determined the relevance of the researcher best-bet technology versus alternative practices such as the choice of varieties, or practices that reduced risk or investment costs (cf. Adjei-Nsiah et al., 2008; Pedzisa et al., 2010; Vandeplas et al., 2010). Gender played a role in the evaluation of varieties and in the use of practices, similar to findings of Doss (2001), Peterman et al. (2014) and Pircher et al. (2013).

Although the household characteristics that indicated the suitability of certain options were useful in a descriptive way, many of the relationships were inconsistent across years (Chapters 2, 3 and 4). Apparently, other variables also played a role in farmers' seasonal decisions to use the options – such as the aforementioned changes in market conditions, weather, pest and disease pressure or varying access to resources cutting across farm types. Predicting the benefits and use of options based on household characteristics therefore remained difficult. Based on this I conclude that broad-level recommendation domains at the regional level are useful for targeting e.g. climbing beans to cooler and wetter highland areas and soybeans to warmer and drier savannah areas, or capital intensive options only to areas with good market access. The search for finer level recommendations based on household characteristics to target technologies was, based on our data, not useful. The observed complexity strengthened the plea for a basket of options from which farmers can select the practices that they prefer. This basket can still include practices tailored to e.g. land or capital constraints, but farmers may vary their decision to apply these practices from season to season. Such an approach is more useful than aiming to develop narrowly specified technology packages (fixed combinations of practices) for every type of farmer. The advantage of a basket of options is also that when farmers gain better access to resources, or when changes at market and institutional level occur, constraints may be relieved and farmers can consider options that were initially out of reach.

6.4 Relationship between co-design process and adoption

Through the inclusion of users' perspectives in the development of technologies (Chapters 3, 4 and 5), we aimed to develop locally relevant technologies and assumed that this would enhance adoption compared with a traditional 'transfer-of-technology' approach (Darnhofer et al., 2012; Jones et al., 2014). Although we did not have an alternative technology development and dissemination model to compare with, we can still compare the evaluation and use of the researcher best-bet technology and practices – assumed to be similar to the transfer-of-technology approach – with the alternative options. In Chapter 4 we showed that only 1% of the farmers used the researcher best-bet technology, and 99% of the farmers adapted the technology. In the comparison of the researcher best-bet practices (improved variety, TSP, row planting) with the alternative options (local varieties, DAP, broadcasting, see Table 3.2), farmers used many of the alternatives more often than the researcher best-bet practices. Most of these alternatives were not entirely new innovations, but existing practices that appeared to have more local relevance in terms of taste, marketability, availability or labour demand than the researcher best-bet (cf. Pedzisa et al., 2010). Alternative staking methods were added as an innovation. However, the options were barely used in practice and thus turned out to be less relevant than initially thought. The development of management recommendations for farmers growing climbing beans in intercropping was another innovation, and can be an avenue for further research (cf. Ntamwira, 2013; Isaacs et al., 2016). Our findings show that just considering the researcher best-bet in technology dissemination is too narrow and may raise misleading expectations about potential improvements in yield when farmers apply different combinations of practices on their own fields (Andersson and D'Souza, 2014; Pedzisa et al., 2015; Brown et al., 2017). Moreover, the attention for farmers adapting technologies provided much richer insights in the relevance of technologies than simply looking at the number of farmers adopting a technology at a certain point in time.

A second assumption was that Chapter 3 would lead to the development of relevant options for different types of farmers, and that farmers would subsequently use these options (Chapter 4). In Chapter 3 we were able to identify such options, including different varieties for farmers producing for home consumption or sale, different inputs for farmers with capital constraints, intercropping for land constrained farmers and broadcasting for labour constrained farmers (Fig. 3.5). However, the actual use of these options was not related to these variables (only the use of organic inputs was related to wealth indicators farm size and livestock ownership, Table 4.7). And as mentioned above, the alternative staking methods were not used at all. Again, this showed that even though we could develop options for different types of farmers, this told us little about the actual use of these options among these types.

Thirdly, we assumed that the co-design process and understanding the use and adaptation of options would lead to 'best-fit' options not only at the field (Chapter 4) but also at the farm level (Chapter 5). The farm-level analysis showed how intercropping of climbing beans in banana/ coffee home gardens makes a lot of sense for land- and capital-constrained farmers. The option of maize stalks as alternative staking material for poorer farmers was included in the basket of options (Chapter 3), and its farm-level suitability considering minimal investment costs and reasonable profit was confirmed in Chapter 5. Discussions with farmers also revealed, however, that other farm-level considerations (not linked to capital or labour) such as the timing of crop rotations and the elevation of fields played a role in the consideration of this option. This was an additional insight gleaned from the farm-level analysis. Finally, field-level comparisons between bush and climbing bean would easily lead to the conclusion that climbing bean cultivation would improve yields compared with bush beans (Checa and Blair, 2012; Musoni et al., 2014). At the farm level, climbing beans showed to require considerable additional costs and labour which not all farmers may be able to afford. In contrast, the favourable developments in market prices of climbing bean in the eastern highlands compared with maize and bush bean made the crop more attractive than initially thought based on Chapter 4. Although such considerations were mentioned during the co-design process, the farm-level analysis further helped to explain why certain choices that seem obvious at field level, may work out differently at the farm level (Franke et al., 2014; Klapwijk et al., 2014; Pannell et al., 2014).

6.5 How to include users' perspectives in large-scale dissemination projects?

The inclusion of users' perspectives in technology development in this thesis yielded insights such as the importance of intercropping, the constraints to the application of alternative staking methods and the reasons for preference of particular varieties. Although the importance of such perspectives is acknowledged (Johnson et al., 2001; Kamanga et al., 2014; Isaacs et al., 2016), there are also trade-offs between a certain level of detail and the time invested. In large-scale research-for-development projects such time and research capacity may not be available (Snapp et al., 2002a). In this section, I therefore provide a practical framework for applying principles derived from this thesis in future studies (Fig. 6.3).

First, the system of demonstration and adaptation trials (Fig. 6.3; Step 1) (similar to 'mother and baby trials') allows farmers to observe multiple options, and try out one or some of them on their own field (Snapp, 2002; Paul et al., 2014).

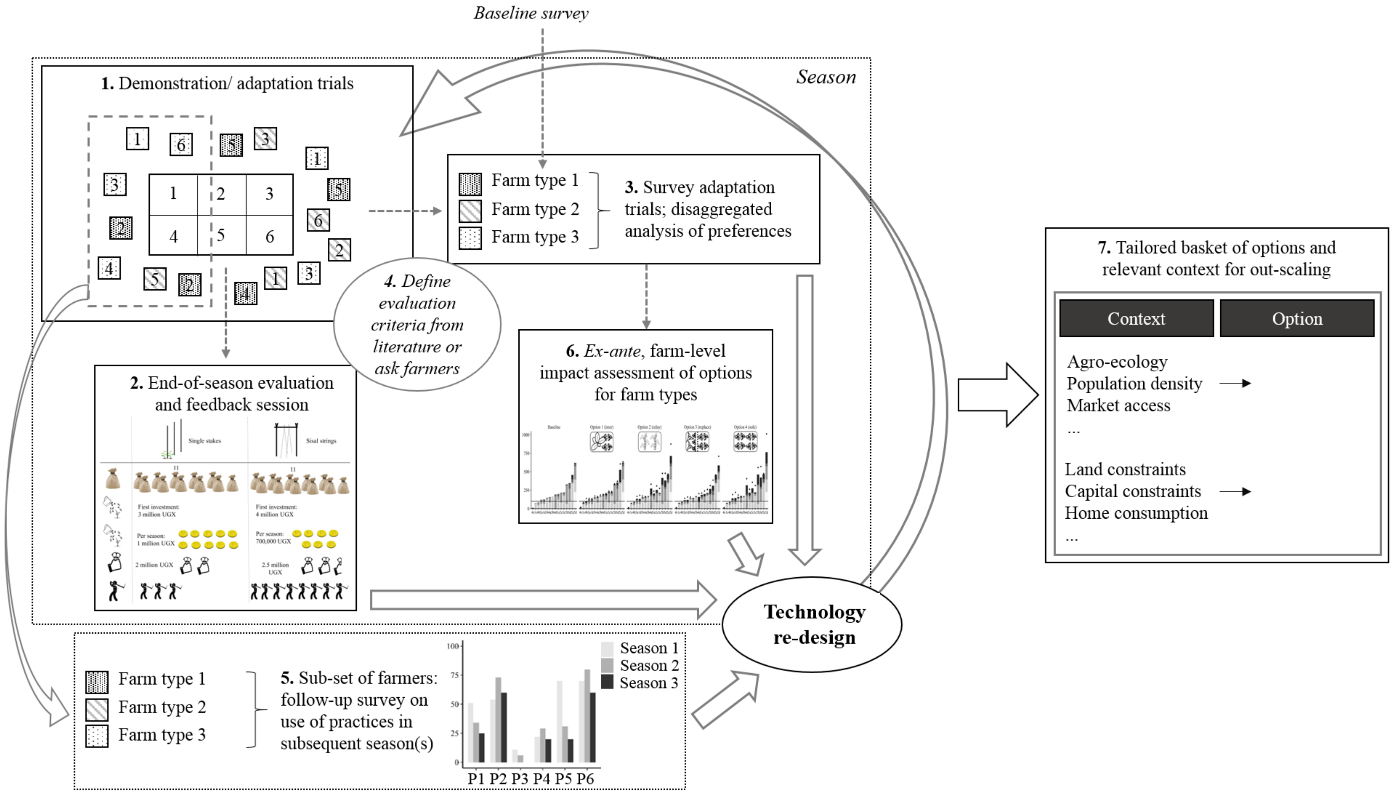


Fig. 6.3: Framework with seven steps for the inclusion of users' perspectives in technology development within large-scale research-for-development projects and the out-scaling of results, based on methods and principles applied in this thesis. Numbers in Step 1 represent treatments in the demonstration and farmers testing these treatments on their own field in adaptation trials. In Step 5, P = practice.

A general evaluation of treatments in the mother trial could be conducted to provide insight in and compare different options (Fig. 6.3; Step 2). Such evaluations can be held during a field day, or after harvest so that calculations of yield, costs and benefits and labour requirements could also be presented (Fig. 6.4). Farmers participating in the adaptation trials can be asked to evaluate the specific option that they selected on their own field. This can be done with a random sub-set of farmers through a short survey with household characteristics, farm and field information and farmers' evaluation of the treatment on multiple criteria (variety traits, costs and availability of inputs, labour requirements, etc.). These evaluations allow for a disaggregation of evaluation results, and relevant sub-groups of farmers preferring a certain treatment can be distinguished (Fig. 6.3; Step 3). Variables to distinguish these sub-groups can be based on region and technology-specific considerations.

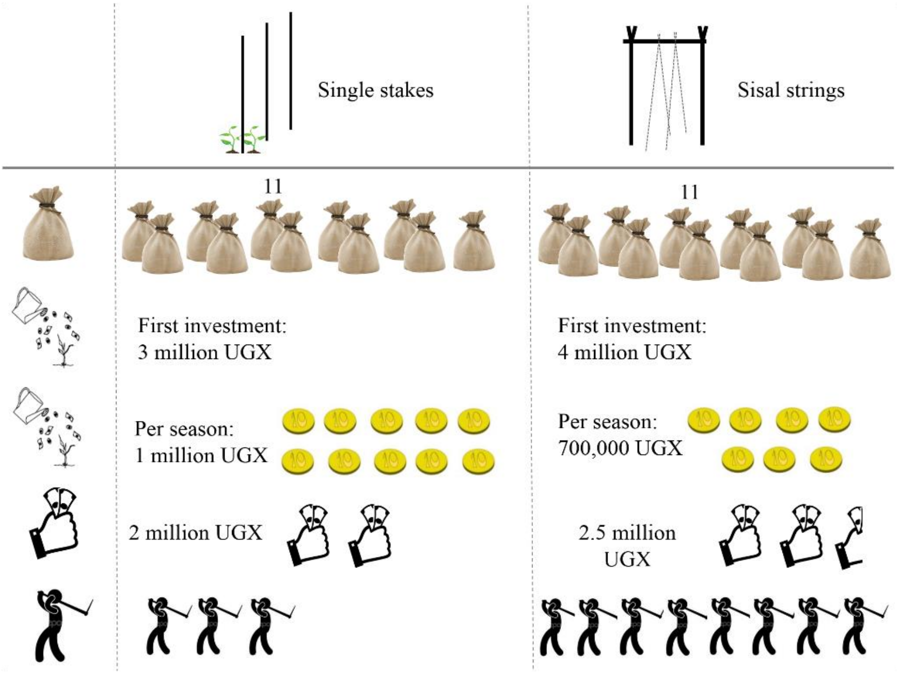


Fig. 6.4: Example of feedback on performance of treatments in a demonstration ('mother trial') in terms of yield, investment costs, profit and labour requirements (presenting results of demonstrations in the southwestern highlands of Uganda, season 2015A)

Second, the scoring of importance of evaluation criteria confirmed that farmers use a wider range of criteria than yield only. For varieties and inputs, previous studies give a good indication of commonly important criteria (Vandeplas et al., 2010; Misiko, 2013; Kamanga et al., 2014). However, for new technologies or practices (such as the staking methods), it is still useful to identify criteria which are particularly important for that technology (Fig. 6.3; Step 4) (Bellon, 2001; Nelson and Coe, 2014).

Third, applying the co-design process over multiple seasons allowed farmers to test the technologies on their own field and to provide feedback. Whereas use and adaptation of practices is often monitored to explain adoption (Nelson and Coe, 2014), we explicitly used the information obtained in the technology development process to identify priorities for further research (Fig. 6.3; Step 5) (Versteeg et al., 1998; Snapp et al., 2002a; Falconnier et al., 2017). Similarly, the (participatory) *ex-ante* assessment of farm-level implications can also help to identify such priorities and distinguish between options that are more or less suitable for different types of farmers (Fig. 6.3; Step 6) (Franke et al., 2014; Schindler et al., 2016).

Finally, although aspects of co-design and understanding adoption are time-consuming (particularly Steps 5 and 6), research outputs can be used for out-scaling to similar areas (Fig. 6.3; Step 7). In our case, the basket of options, through the addition of relevant contexts in Fig. 3.5, can be used as a starting point for other projects across the East-African highlands. Results developed after (resource-intensive) interactions with a limited group of farmers are therefore relevant for out-scaling to larger numbers of beneficiaries (Conroy and Sutherland, 2004; Falconnier et al., 2017). Hence, it is not needed to apply an intensive co-design process in every new area. Similarly, the ‘complex’ nature of climbing beans (i.e. the combination of multiple practices) makes efforts to tailor the technology more necessary than for simpler technologies with less room for manoeuvre (cf. Sumberg et al., 2003). Moreover, researchers’ improved understanding of farming systems and farmers’ needs and constraints after participating in a co-design process could speed up the development of new technologies in similar systems. The required intensity of interactions therefore depends on the nature of technologies, and may diminish over time.

6.6 Limitations of the study

This study was conducted in the context of a large-scale project focusing on research on and dissemination of legumes (Giller et al., 2013). This context enabled the analysis of yield data collected from a wide range of environmental and management conditions which are representative for smallholder farmers’ conditions (Chapters 2 and 4). Yet, the approach also resulted in unbalanced data which limited the number of observations or variables that we could include in statistical analyses. Moreover, variables were often confounded. Measurements of shelled, oven-dried grain weights could also have reduced unexplained variability in yields. However, such measurements are laborious, expensive and hard to coordinate with laboratories when applied at large scale. These limitations reflect a trade-off between large-scale assessment of the performance of technologies under farmers’ conditions, and understanding the effects of particular factors on yield.

Explanatory variables used in this study were based on earlier studies on understanding farmer diversity (Tittonell et al., 2010; Giller et al., 2011) or adoption (Feder and Umali, 1993; Farrow et al., 2016). We could have missed important variables that would have increased the percentage of variability explained, such as site-specific rainfall data, information on pests and diseases and farmers' own explanation of differences in yields (Bielders and Gérard, 2014; Falconnier et al., 2016). To understand adoption, we could have included a whole range of other variables that can be found in the large body of literature on the adoption of technologies. A larger number of explanatory variables would have required a much larger sample size. A larger sample size would probably also result in better consistency with explanatory variables. However, although correlations between variables can highlight constraints for adoption, they offer little insight in farmers' motivations or guidance on how to enhance the relevance of technologies (cf. Tadesse et al., 2017). Formal and informal discussions with farmers proved a valuable addition in our case.

In this study we concluded that household characteristics or farm typologies were of limited value to explain and predict differences in yield, preferences, use and effects of different options. Yet, a diversity of methods was used within and between chapters to establish preferences (Chapter 3) and farm typologies (Chapters 3, 4, 5). Although the search for the 'best' evaluation method in Chapter 3 was part of the objectives of the study, a consistent method applied over multiple seasons may have provided more robust conclusions. With respect to farm types, we aimed to develop a typology similar to the one used in Chapter 5, for Chapters 3 and 4 as well. A Multiple Correspondence Analysis and hierarchical clustering were applied, but resulted in highly unstable clusters (i.e. small changes resulted in an entirely different typology). A more thorough farm characterization exercise could have resulted in a more consistent typology, but such an approach is difficult to apply at the scale that we worked, including yearly extension to new areas as part of the project design. These different approaches made comparisons between the chapters harder, although all approaches relied on similar household characteristics (cf. Table 4.5 and 5.1).

Finally, the limited differences in preference, use and effects of different options for climbing bean cultivation could indicate that the options developed were not so different (e.g. not completely unsuitable for certain types of farmers). More extreme differences in options, including different crops or other livelihood activities (see Dogliotti et al., 2014; Descheemaeker et al., 2016a; Falconnier et al., 2017) could have resulted in more pronounced preferences and effects.

6.7 Concluding remarks and implications for future research

At the start of this study, I expected to be able to recommend specific options for legume cultivation for different types of farmers. Throughout the thesis, however, I was confronted with variability in results, and weak or inconsistent relationships with explanatory variables.

Based on this thesis I therefore conclude that although farm typologies were relevant to describe farmer diversity, they poorly predicted performance, preference, use or impact of legume technologies and were not useful as a basis for recommendations for targeting of technologies. One-off typologies give insufficient insight in the season-to-season dynamics that also play a role in farmers' decision making, and it is probably an illusion to think that we could capture all these dynamics to formulate better typologies. A basket of options, tailored to local conditions and allowing flexible application of different combinations of practices, was therefore judged to be more useful than narrowly specified technologies for pre-defined farm types. Only recommendation domains at the regional level were considered to have predictive value for targeting of technologies.

My research was conducted in the context of a large-scale legume dissemination project, N2Africa. This allowed assessment of the performance of legume technologies on farmers' fields under a wide range of environments and management conditions, rather than under the optimal conditions on research stations. The results of this testing demonstrated a strong variability in yields, and emphasized the need to look beyond average performance (cf. Vanlauwe et al., 2016). At the same time, it proved hard to understand this variability and to describe the conditions under which technologies perform well. Partly, this may be related to challenges associated with conducting research in such a large-scale project. Explanatory variables were confounded, data were unbalanced and some environmental and management factors may not have been captured accurately. Late planting sometimes resulted in poor yields and responses, irrespective of agro-ecological or household characteristics. In future research, adaptation trials are still considered useful to assess the 'likelihood of success' and the profitability of technologies under variable conditions. The effects of particular factors on yield, however, are better understood under more homogenous conditions in researcher-managed – but on farm and multi-locational – trials.

In this study I specifically aimed to develop suitable options for resource-poor farmers, but realized that the multiple constraints that these farmers face cannot be addressed without considering institutional change to improve access to land, labour and capital; to reliable input and output markets; or to improve trust and collective action. Despite the limited opportunities for poorer farmers it remains important to think about agricultural innovations that can improve productivity under current conditions, and how to deliver these innovations. In this thesis I also showed, however, that a potential improvement in yield is only one of farmers' criteria for adoption of technologies, next to e.g. other variety traits; costs, availability and the ease of application of inputs and management practices; and farm-level resource allocation decisions. An assessment of the performance of technologies on farmers' fields should therefore be combined with a proper understanding of farmers' reasons for (non-)use of technologies – not only to explain adoption but as integral part of technology development. The concept of farmers adapting, instead of adopting technologies can enrich such understanding. Hence, it is not enough for agronomists to focus on improving yields at field level, but also on how to make technologies work at the farm level within a diversity of livelihood activities. Only then will their work contribute to improving agricultural production among smallholder farmers.

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Annex

Annex A: Co-design of improved climbing bean production practices for smallholder farmers in the highlands of Uganda

Annex B: Farmers’ use and adaptation of improved climbing bean production practices in the highlands of Uganda

Annex C: How do climbing beans fit in farming systems of the eastern highlands of Uganda? Understanding opportunities and constraints at farm level

Annex A

Table A1: Varieties, inputs, staking methods and other practices shown in demonstrations in the eastern and southwestern highlands of Uganda in seasons 2014A, 2014B, 2015A and 2015B

Variety	Inputs			Staking method	Other practice	Region and season	
	Manure	TSP	DAP			Eastern	Southwestern
Kabale local	-	-	-	Single stakes	Row planting	2014A, 2014B	2014B
Kabale local	+	-	-	Single stakes	Row planting	2014B	2014B
Kabale local	-	+	-	Single stakes	Row planting	2014B	2014B
Kabale local	+	+	-	Single stakes	Row planting	2014A, 2014B, 2015A, 2015B	2014B
Kabale local	+	+	-	Tripods	Row planting	2014B	2014B
Katuna	-	-	-	Single stakes	Row planting	NA	2015A, 2015B
Katuna	-	+	-	Single stakes	Row planting	NA	2015B
Katuna	+	+	-	Single stakes	Row planting	NA	2015A, 2015B
NABE 10C	+	+	-	Single stakes	Row planting	2015A, 2015B	NA
NABE 12C	-	-	-	Single stakes	Row planting	2014B, 2015A, 2015B	2014B, 2015A, 2015B
NABE 12C	+	-	-	Single stakes	Row planting	2014B	2014B, 2015A, 2015B
NABE 12C	-	+	-	Single stakes	Row planting	2014B, 2015A, 2015B	2014B, 2015A, 2015B
NABE 12C	-	+	-	Sisal strings	Row planting	2015A, 2015B	NA
NABE 12C	-	+	-	Tripods	Row planting	2015A, 2015B	NA
NABE 12C	-	-	+	Single stakes	Row planting	2015A, 2015B	NA
NABE 12C	+	+	-	Single stakes	Row planting	2014B, 2015A, 2015B	2014B, 2015A, 2015B
NABE 12C	+	+	-	Sisal strings	Row planting	2014B	2014B, 2015A, 2015B
NABE 12C	+	+	-	Tripods	Row planting	2014B	2014B
NABE 12C	+	+	-	Single stakes	Broadcasting	NA	2015A, 2015B

Variety	Inputs			Staking method	Other practice	Region and season	
	Manure	TSP	DAP			Eastern	Southwestern
NABE 12C	+	+	-	Single stakes	Remove growing tip	NA	2015A, 2015B
NABE 26C	-	-	-	Single stakes	Row planting	2014A	2015A
NABE 26C	+	+	-	Single stakes	Row planting	2014A, 2015A	2015A
NABE 26C	+	+	-	Banana fibre ropes	Row planting	2014A	NA
NABE 26C	+	+	-	Sisal strings	Row planting	2014A	NA
NABE 26C	+	+	-	Tripods	Row planting	2014A	NA
Fe-enriched	-	-	-	Single stakes	Row planting	NA	2015A, 2015B
Fe-enriched	-	+	-	Single stakes	Row planting	NA	2015B
Fe-enriched	+	+	-	Single stakes	Row planting	2015A, 2015B	2015A, 2015B

A2: Developing an 'attainment index' for technology evaluation

"The attainment index is a measure of the extent to which the overall performance of a technology option meets the interests and needs of a farmer or group of farmers" (Bellon, 2001). Farmers first scored the importance of a number of criteria for technology evaluation, followed by the scoring of the performance of treatments on each of these criteria. The attainment index was calculated based on the logic outlined by Bellon (2001): criteria were scored as 1 = very important, 0.4 = somewhat important, and 0 = not important; the performance of treatments for each criterion was scored as 1 = good, 0.5 = medium, and -1 = poor. The score of 0.4 for "somewhat important" was given to produce the ordering shown in Table S2, following the assumption that it is more desirable to have an intermediate performance for a very important characteristic than to have a very good performance for a characteristic that is "somewhat important." Scores for performance and criteria can be combined in a matrix that produces an ordinal scale from more to less desirable. For each cell in the matrix the scores were multiplied, to obtain a combined score ranging between 1 and -1 (Table S3.2).

Table A2: Matrix of scores for attainment index

Performance	Importance of criteria		
	Very important (= 1)	Somewhat important (= 0.4)	Not important (= 0)
Very good (= 1)	1	0.4	0
Intermediate (= 0.5)	0.5	0.2	0
Poor (= -1)	-1	-0.4	0

Source: Bellon (2001)

The combined scores for all criteria were added to generate an overall weighted score per treatment: the attainment index. As some farmers may have rated a larger number of criteria as important than others, the index was normalized and divided by a 'perfect score' – the score that would have been obtained if the treatment had scored 'good' on all relevant criteria (the sum of 'very' and 'somewhat important' scores).

Table A3: Average score for importance of evaluation criteria (1 = very; 0 = somewhat; -1 = not important) in the eastern (E) and southwestern (SW) highlands of Uganda in season 2015A, and household characteristics having a significant ($P < 0.05$) positive or negative relationship with this score (region where relationship was significant indicated in brackets). * indicates significant difference in importance of criteria between regions ($P < 0.05$).

Category	Criteria	Score		Household characteristic	Pos./
		E	SW	(region)	neg.
General	Yield	0.92	0.93		
	Costs	0.42*	0.82*	Proportion income farming (E)	-
				Farm size (SW)	+
				Production orientation (SW)	-
	Benefit/cost ratio	0.79	0.75	Production orientation (SW)	-
	Labour	0.87*	0.55*		
Varieties	Yield without fertilizer	0.92*	0.26*	Income from salary/pension/ remittances (E)	-
				Proportion income farming (SW)	+
	Yield with fertilizer	0.87	0.82	Age hh head (SW)	-
				Farm size (SW)	-
				Income from salary/pension/ remittances (SW)	-
	Grain size	0.92	0.85		
	Grain colour	1.00	0.83		
	Marketability	0.66*	0.96*		
	Taste	0.79	0.93		
	Maturity time	0.76	0.88	Production orientation (SW)	+
	Tolerance insects	0.79	0.73		
	Tolerance other pests	0.87	0.62		
	Resistance disease	0.97	0.84	Farm size (SW)	+
	Suitability for climate	1.00	0.89		
Inputs	Availability inputs	0.95*	0.52*		
Staking methods	Ease of staking method	1.00	0.96		
	Availability staking material	1.00	0.57		
	Strength of staking material	1.00	0.88	Age household head (SW)	-
	Re-usability staking material	1.00	0.98		

Annex B

Table B1: Varieties, inputs, staking and planting methods shown in demonstration trials in Kabale, Kanungu and Kapchorwa Districts per season

Variety	Cattle manure	TSP	DAP	Staking method	Planting method	Kabale and Kanungu	Kapchorwa	Source of practice
NABE 12C	-	-	-	Single stakes	Row planting	2015A, 2015B	2014B, 2015A, 2015B	Research
NABE 12C	+	-	-	Single stakes	Row planting	2015A, 2015B	2014B	Research
NABE 12C	-	+	-	Single stakes	Row planting	2015A, 2015B	2014B, 2015A, 2015B	Research
NABE 12C	+	+	-	Single stakes	Row planting	2015A, 2015B	2014B, 2015A, 2015B	Research
NABE 12C	-	-	+	Single stakes	Row planting	NA	2015A, 2015B	Co-design
Local Kabale	-	-	-	Single stakes	Row planting	NA	2014B	Research
Local Kabale	+	-	-	Single stakes	Row planting	NA	2014B	Research
Local Kabale	-	+	-	Single stakes	Row planting	NA	2014B	Research
Local Kabale	+	+	-	Single stakes	Row planting	NA	2014B, 2015A, 2015B	Research
NABE 10C	+	+	-	Single stakes	Row planting	NA	2015A, 2015B	Co-design
Nabe 26C	-	-	-	Single stakes	Row planting	2015A	NA	Research
NABE 26C	+	+	-	Single stakes	Row planting	2015A	2015A	Research
Fe-enriched	+	+	-	Single stakes	Row planting	2015A, 2015B	2015A, 2015B	Research
Fe-enriched	-	-	-	Single stakes	Row planting	2015A, 2015B	NA	Research
Fe-enriched	-	+	-	Single stakes	Row planting	2015B	NA	Research
Katuna	-	-	-	Single stakes	Row planting	2015A, 2015B	NA	Co-design
Katuna	-	+	-	Single stakes	Row planting	2015B	NA	Co-design
Katuna	+	+	-	Single stakes	Row planting	2015A, 2015B	NA	Co-design

Variety	Cattle manure	TSP	DAP	Staking method	Planting method	Kabale and Kanungu	Kapchorwa	Source of practice
NABE 12C	+	+	-	Tripods	Row planting	NA	2014B	Co-design
NABE 12C	+	+	-	Strings	Row planting	2015A, 2015B	2014B	Co-design
NABE 12C	-	+	-	Tripods	Row planting	NA	2015A, 2015B	Co-design
NABE 12C	-	+	-	Strings	Row planting	NA	2015A, 2015B	Co-design
Local Kabale	+	+	-	Tripods	Row planting	NA	2014B	Co-design
Nabe 12C	+	+	-	Single stakes	Broadcasting	2015A, 2015B	NA	Co-design

Annex C

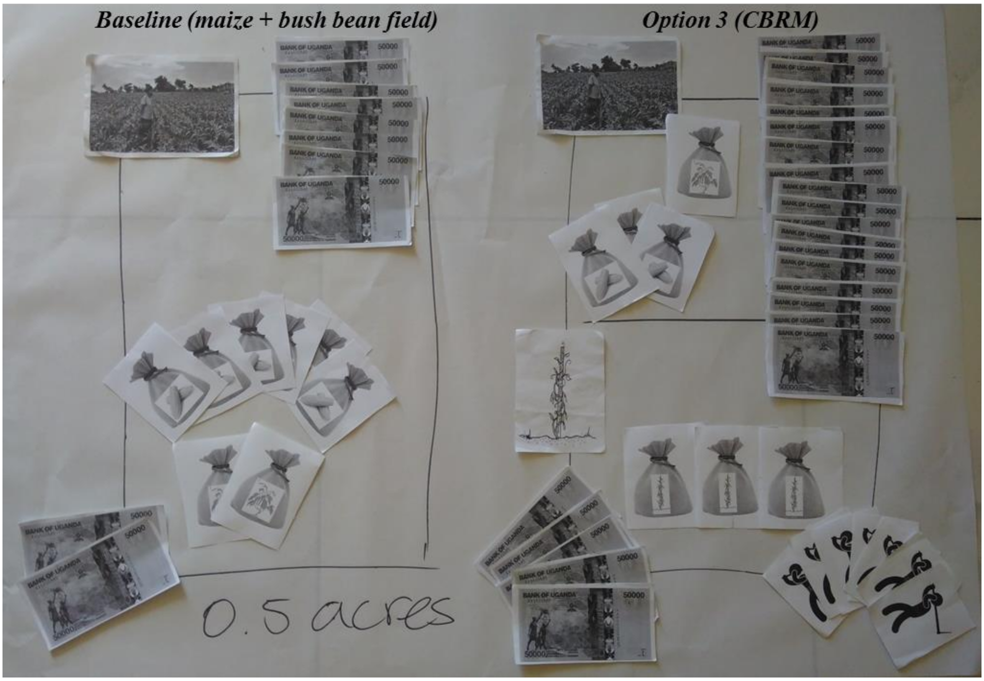

Fig. C1: Example of drawings and symbols used to facilitate the discussion of options with farmers. Baseline situation (field with maize + bush bean) was compared with Option 3 (replace) by stepwise addition of the indicators crop yield, income, investment costs and labour.

Table C1: Soil fertility parameters of fields with the most commonly cultivated crops in the detailed characterization

Main crop	n	Fertility class*	pH (H_2O)	OC (g kg^{-1})	Total N (g kg^{-1})	P Mehlich (mg kg^{-1})	Exch. K (cmol + kg^{-1})	Exch. Ca (cmol + kg^{-1})	Exch. Mg (cmol + kg^{-1})	% Clay + silt
Climbing bean intercropping	6	2.2	6.5	37	3.3	21.0	1.6	26.7	13.1	72
Climbing bean sole cropping	4	2.0	6.2	42	3.8	14.1	1.4	23.8	12.6	66
Banana/ coffee	13	2.2	6.4	38	3.6	17.3	1.9	24.6	13.2	73
Maize + bush bean**	16	2.5	6.4	33	2.8	26.8	1.4	26.7	14.8	70
Total/ average	39	2.3	6.4	36	3.3	21.3	1.6	25.6	13.8	71
P-*values*		*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	< 0.05	*ns*

* *Farmer estimated soil fertility (1 = poor, 2 = medium, 3 = good)*

** *Includes one field with Irish potato. Taken together as common rotation is maize and Irish potato on the same field*

Table C2: Annual farm operations per crop per 10-day period. LP = land preparation, SO = sowing, ST = staking, W1-4 = weeding 1-4, HA = harvest.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Climbing bean		LP	SO	ST	W1 W2		HA	LP SO	ST W1		W2	HA
Bush bean		LP		SO	W1 W2		HA	LP	SO	W1	W2	HA
Maize		LP		SO	W1	W2				HA		
Banana		W			W			W				
Irish potato		LP	SO	W1	W2	HA						

Summary

Sustainable intensification of agriculture is needed to achieve necessary increases in food production without increasing environmental impacts. One potential pathway for sustainable intensification is the integration of legumes in farming systems. Legumes can fix nitrogen from the air in symbiosis with *Rhizobium* bacteria and contribute to improved soil fertility and crop yields in cereal-dominated cropping systems in Africa. Current legume yields among African smallholders are far below their potential. To improve legume yields, the relationship between the legume genotype, the agro-ecological environment and agronomic management factors needs to be understood. Understanding this relationship can lead to recommendations about which farmers are likely to benefit most from the technology.

However, even if we understand when and where legumes yield well, this does not mean that farmers will also adopt these legumes. Economic feasibility and socio-cultural acceptability of technologies also plays a role – technologies need to fit within a 'socio-ecological niche'. To fit such niches, technologies may have to be tailored or adapted. Tailoring of technologies requires a thorough understanding of local conditions that may facilitate or constrain adoption, for which it is important to engage the users of the technology. Whereas previous studies have engaged users up to the technology design phase, an iterative co-design cycle in which farmers also get the opportunity to test different options, provide feedback on them and are engaged in the re-design of technologies could improve the relevance of the developed technologies. Following up on farmers who (dis)continue using certain options can serve as a check for the actual relevance of options, and farmers' own adaptations to the options could further inform the re-design of technologies. An analysis of farm-level impact and trade-offs of technologies can improve insights in the suitability of technologies by considering farmers' multiple objectives at the farm level. We applied this combination of approaches to co-design (with farmers, researchers and other stakeholders) a number of tailored, locally relevant options – together considered a 'basket of options' – applicable in particular niches.

The overall objective of this thesis was to identify niches for sustainable intensification of agriculture through legumes for different types of smallholder farmers in sub-Saharan Africa. We first aimed to understand field-level variability in legume yields and response to inputs, and evaluate the consequences of this variability for farmers' (economic) benefits and targeting of technologies (*Chapter 2*). This part of the study was applied to soybeans (*Glycine max* (L.) Merrill) in Nigeria. We evaluated the results of widespread testing of improved soybean varieties with four treatments: no inputs (control); SSP fertilizer (P); inoculants (I) and SSP plus inoculants (P+I) among smallholder farmers in northern Nigeria in 2011 and

2012. We observed a strong response to both P and I, which significantly increased grain yields. The additive effect of P+I resulted in the best average yields. Variability in yield among farms was large, however, which had implications for the benefits for individual farmers. Although the yield response to P and I was similar, I was more profitable due to its low cost. Only 16% of the variability in control yields could be explained (by plant establishment, days to first weeding, percentage sand and soil exchangeable magnesium), and between 42% and 61% of variability in response to P and/or I (by year, farm size, plant establishment, total rainfall and pH). The predictive value of these variables was limited, however, with cross-validation R^2 decreasing to about 15% for the prediction between districts and 10% between seasons. We concluded that averages of performance of technologies tell little about the adoption potential for individual farmers, and that the poor predictability of yields from one district or season to the other complicate the potential for targeting of technologies.

Realizing that understanding where technologies work best does not necessarily lead to adoption of these technologies, Chapters 3, 4 and 5 focused on the co-design, use and farm-level opportunities and constraints for legume technologies for different types of farmers. This part of the study was applied to climbing beans (*Phaseolus vulgaris* L.) in the highlands of Uganda. Climbing beans were considered an interesting example for a co-design process because they are a relatively new crop, require a change in cropping system compared with the more widely grown bush bean and need considerable investments in staking material to realize their potential yield advantage over bush beans. Hence, climbing beans are a ‘complex technology’, consisting of different components or practices which can all be tailored.

We evaluated the usefulness of a co-design process to generate a relevant basket of options for climbing bean cultivation for a diversity of farmers in *Chapter 3*. The co-design process consisted of three cycles of demonstration, evaluation and re-design in the eastern and southwestern highlands of Uganda in 2014-2015. Evaluations aimed to distinguish between preferences of farmers in the two highland areas, and between preferences of farmers of different gender and socio-economic background. Climbing bean yields and farmers’ evaluations of treatments in the demonstrations varied between seasons and sites. Evaluation scores were not always in line with yields, and reasons for preference of treatments revealed that farmers used multiple evaluation criteria next to yield, such as marketability of varieties, availability of inputs and ease of staking methods. The co-design process enriched the basket of options, improved the relevance of the demonstrated options and enhanced the understanding of preferences of a diversity of users. Developing options for resource-poor farmers was difficult, however, because these farmers face multiple constraints. The basket of options developed in this study can be applied across the East-African highlands, with an ‘option-by-context’ matrix as a potential tool for out-scaling. The study also showed, however, that consistent recommendations based on household characteristics were difficult to formulate.

In *Chapter 4*, we studied the uptake of the co-designed options for climbing bean cultivation among 374 smallholder farmers participating in farmer-managed adaptation trials in the eastern and southwestern highlands of Uganda. A sub-set of these farmers was monitored one to three seasons after their participation. About 70% of the farmers re-planted climbing beans one season after the adaptation trial, with significant differences between the eastern (50%) and southwestern highlands (80-90%). The combination of practices (varieties, inputs and other management practices) that was expected to lead to the largest yields – the researcher best-bet technology – was applied by only 1% of the farmers; 99% adapted the technology. Yield variability of the trials was large and on average, trial plots did not yield more than farmers' own climbing bean plots. Yet, achieved yields did not influence whether farmers continued to cultivate climbing bean in the subsequent season. Uptake of climbing beans varied with household characteristics: poorer farmers cultivated climbing beans more often but used fewer of the best-bet practices, and male farmers generally used more practices than female farmers. Planting by poorer farmers resulted in adaptations such as growing climbing beans without fertilizer and with fewer and shorter stakes. Other relationships with household characteristics were inconsistent and farmers changed practices from season to season. This showed that the adoption of technologies consisting of multiple components is a process that is hard to capture through the monitoring of farmers' use of the technology at a single point in time. Furthermore, just as in Chapter 3, the inconsistencies in farmers' use of practices and in relationships with explanatory variables complicated the formulation of recommendations about the suitability of technologies for different types of farmers.

Farm-level opportunities, constraints and trade-offs for climbing bean cultivation were assessed in *Chapter 5*. This chapter focused on the eastern highlands only, as climbing beans were new for most farmers in this area whereas farmers in the southwest appeared to have used them for a longer period of time already. For farmers in the eastern highlands, we established current food self-sufficiency, income, investment costs and labour input, and assessed the *ex-ante*, farm-level impact of four climbing bean options on these indicators. Input for this assessment were a detailed characterization of 16 farms of four types, and results of the climbing bean adaptation trials of Chapter 4. Climbing beans generally improved food self-sufficiency and income, but often required increased investment and always demanded more labour than current farm configurations. The small farm sizes of the poorest farm types restricted the options for the inclusion of climbing beans compared with larger farms. Moreover, poorer farmers may be unable to make the necessary investments in climbing bean cultivation. The analysis was translated into a simple-to-use modelling tool to enable participatory analysis of the outcomes with the four farm types and understand their perspectives and decision-making. The discussions revealed a recent increase in market prices for climbing bean, resulting in growing interest in their cultivation. A lack of seed and stakes were limiting climbing bean cultivation. To enhance climbing bean cultivation in the area, larger volumes of seed need to be produced and made available through strengthening of farmer cooperatives and improved storage.

Each of the four research chapters in this thesis started from the assumption that it would be possible to recommend specific options for legume cultivation for different types of farmers, with differences between farmers mainly relating to agro-ecological and socio-economic variables. Throughout the chapters, however, we were confronted with variability and inconsistencies in explanatory relationships which complicated the formulation of recommendations about the suitability of technologies for different types of farmers. We therefore concluded that farm typologies were relevant to describe farmer diversity, but poorly predicted performance, preference, adoption or effects of legume technologies. A basket of options, tailored to local conditions, was judged to be more useful than narrowly specified technologies for pre-defined farm types.

The inclusion of users' perspectives in technology development yielded insights such as the importance of climbing bean intercropping and the constraints to the application of alternative staking methods. Although the importance of the inclusion of such perspectives is acknowledged, there were trade-offs between the level of detail and the time invested in obtaining these perspectives. The incorporation of farmers' evaluations of demonstration trials in technology re-design, as well as their feedback on the testing of technologies on their own field – disaggregated to farm types – were considered two components of this study that are relatively easy to apply in other large-scale research-for-development projects. Moreover, results developed after (resource-intensive) interactions with a limited group of farmers can be used for out-scaling to larger numbers of beneficiaries. Hence, it is not needed to apply an intensive co-design process in every new area. Options to improve the benefits of legume technologies for poorer farmers were limited in this thesis. Agricultural innovations therefore need to go hand in hand with institutional innovation to truly impact the livelihoods of poor farmers.

Samenvatting

Duurzame intensivering van de landbouw is nodig om de noodzakelijke stijging van voedselproductie te bereiken, zonder negatieve gevolgen voor het milieu. Een mogelijkheid voor duurzame intensivering is de integratie van peulvruchten in landbouwsystemen. Peulvruchten kunnen stikstof uit de lucht binden in symbiose met *Rhizobium* bacteriën en kunnen bijdragen aan een verbeterde bodemvruchtbaarheid en gewasopbrengsten in door granen gedomineerde teeltsystemen in Afrika. De huidige opbrengst van peulvruchten ligt bij Afrikaanse, kleinschalige boeren ver onder hun potentieel. Om de opbrengst van peulvruchten te verbeteren moet de relatie tussen het genotype van de peulvrucht, de agro-ecologische omgeving en het agronomisch beheer worden begrepen. Dit begrip kan leiden tot aanbevelingen over welke technologieën het meest relevant zijn voor welke boeren.

Echter, zelfs als we begrijpen waar en wanneer peulvruchten het goed doen, betekent dit niet dat boeren deze gewassen ook gaan gebruiken. De economische haalbaarheid en sociaal-culturele acceptatie van technologieën speelt ook een rol: technologieën moeten passen binnen een 'sociaal-ecologische niche'. Om in dergelijke niches te passen, moeten de technologieën mogelijk worden aangepast. Het aanpassen van technologieën vereist een grondig begrip van de lokale omstandigheden die adoptie mogelijk maken of bemoeilijken, waarvoor het belangrijk is om de gebruikers van de technologie in het onderzoek te betrekken. Waar eerdere onderzoeken gebruikers hebben betrokken tot aan de fase van het technologisch ontwerp, past dit onderzoek een iteratieve, gezamenlijke ontwerpcyclus toe. Hierin krijgen boeren ook de kans om verschillende opties te testen, feedback te geven en aanpassingen aan te brengen, waardoor de relevantie van technologieën verbetert. Het opvolgen van boeren die bepaalde opties (niet langer) gebruiken, kan als test dienen voor de werkelijke relevantie van die opties, en de eigen aanpassingen van boeren kunnen het herontwerp van technologieën verder informeren. Een analyse van de effecten en compromissen van technologieën op bedrijfsniveau kan het inzicht in de geschiktheid van technologieën verbeteren door rekening te houden met de verschillende doelstellingen die boeren hebben op dit niveau. We hebben deze combinatie van benaderingen toegepast om tot een gezamenlijk ontwerp (met boeren, onderzoekers en andere belanghebbenden) van een aantal aangepaste, lokaal relevante opties te komen – samen beschouwd als een ‘pakket met opties’ – die toegepast kunnen worden in bepaalde niches.

De algemene doelstelling van dit proefschrift was om niches te identificeren voor duurzame intensivering van de landbouw via peulvruchten voor verschillende typen kleinschalige boeren in sub-Sahara Afrika. We wilden eerst de variabiliteit in peulvruchtopbrengsten en de respons op inputs op veldniveau begrijpen, evenals de consequenties van deze variabiliteit voor de (economische) voordelen voor boeren en het gericht aanbieden van technologieën (*Hoofdstuk 2*). Dit deel van de studie werd toegepast op sojabonen (*Glycine max* (L.) Merrill) in Nigeria. We evalueerden de resultaten van het wijdverspreid testen van verbeterde sojavariëteiten met vier behandelingen: geen inputs (controle); SSP-kunstmest (P); inoculanten (I) en SSP plus inoculanten (P + I) bij kleinschalige boeren in Noord-Nigeria in 2011 en 2012. We zagen een sterke respons op zowel P als I, waardoor de opbrengsten significant toenamen. Het additieve effect van P + I resulteerde in de hoogste gemiddelde opbrengsten. De variabiliteit in opbrengst tussen boeren was echter groot, wat gevolgen heeft voor de voordelen voor individuele boeren. Hoewel de respons op P en I vergelijkbaar was, was I winstgevender vanwege de lage kosten. Slechts 16% van de variabiliteit in de controleopbrengsten kon worden verklaard (door het aantal opgekomen planten, het aantal dagen tot het eerste wieden van onkruid, het percentage zand en de hoeveelheid magnesium in de grond), en tussen 42% en 61% van de variabiliteit in de respons op P en/of I (door jaar, bedrijfsgrootte, het aantal opgekomen planten, totale regenval en pH). De voorspellende waarde van deze variabelen was echter beperkt: in een kruisvalidatie daalde de R^2 tot ongeveer 15% voor het voorspellen tussen districten, en tot 10% tussen seizoenen. We concludeerden dat de gemiddelde prestaties van technologieën weinig zeggen over het potentieel voor adoptie door individuele boeren, en dat de slechte voorspelbaarheid van opbrengsten voor het ene district of seizoen op basis van het andere de mogelijkheid voor het gericht aanbieden van technologieën bemoeilijkt.

Omdat we beseffen dat inzicht in waar technologieën het beste werken niet noodzakelijkerwijs leidt tot adoptie van deze technologieën, concentreerden de hoofdstukken 3, 4 en 5 zich op het gezamenlijk ontwerp, het gebruik, en de mogelijkheden en beperkingen op bedrijfsniveau van technologieën voor peulvruchten voor verschillende typen boeren. Dit deel van het onderzoek werd toegepast op klimbonen (*Phaseolus vulgaris* L.) in de hooglanden van Oeganda. Klimbonen werden beschouwd als een interessant onderwerp van een gezamenlijk ontwerpproces omdat klimbonen een relatief nieuw gewas zijn, ze een verandering vereisen in het gewassysteem vergeleken met de vaker verbouwde stambonen en aanzienlijke investeringen vragen in bonenstaken om hun potentiële opbrengstvoordeel ten opzichte van stambonen te realiseren. Klimbonen vormen daarom een ‘complexe technologie’, die bestaat uit verschillende componenten of landbouwpraktijken die elk aangepast kunnen worden.

In *Hoofdstuk 3* evalueerden we het nut van een gezamenlijk ontwerpproces om tot een relevant pakket met opties voor de verbouw van klimbonen te komen voor verschillende typen boeren. Het ontwerpproces bestond uit drie cycli van demonstratie, evaluatie en herontwerp in de oostelijke en zuidwestelijke hooglanden van Oeganda in 2014-2015. Evaluaties hadden als doel om de voorkeuren van boeren in de twee hooglandgebieden te onderscheiden, en van boeren met verschillende sekse en sociaal-economische achtergrond.

De opbrengsten van klimbonen en de evaluaties van boeren van verschillende behandelingen in de demonstraties varieerden tussen seizoenen en locaties. Evaluatiescores kwamen niet altijd overeen met de opbrengsten, en uit de redenen voor voorkeur van behandelingen bleek dat boeren meerdere beoordelingscriteria gebruikten naast opbrengst, zoals het marktpotentieel van variëteiten, de beschikbaarheid van inputs en het gemak van de verschillende methodes voor het ondersteunen van de bonen met staken. Het gezamenlijk ontwerpproces verrijkte het pakket met opties, verbeterde de relevantie van de getoonde opties en verbeterde het begrip van de voorkeuren van een diversiteit aan gebruikers. Het ontwikkelen van opties voor arme boeren was echter moeilijk, omdat deze boeren te maken hebben met beperkingen op meerdere gebieden. Het pakket met opties dat in dit onderzoek werd ontwikkeld kan worden toegepast in de Oost-Afrikaanse hooglanden, waarbij het vastleggen van opties en hun relevante context in een matrix als een mogelijk hulpmiddel kan dienen voor opschaling van de opties. De studie toonde echter ook aan dat het moeilijk was om consistente aanbevelingen op basis van huishoudenskenmerken te formuleren.

In *Hoofdstuk 4* hebben we het gebruik van de gezamenlijk ontworpen opties voor de verbouw van klimbonen bestudeerd bij 374 kleinschalige boeren, die klimbonen testten in een zelfbeheerde proef op hun eigen veld in de oostelijke en zuidwestelijke hooglanden van Oeganda. Een kleiner deel van deze boeren werd ook één tot drie seizoenen na hun deelname gevolgd. Ongeveer 70% van de boeren plantte de bonen één seizoen na deelname aan de proef opnieuw, met significante verschillen tussen de oostelijke (50%) en zuidwestelijke hooglanden (80-90%). De combinatie van landbouwpraktijken (variëteiten, inputs en andere beheersmaatregelen) die naar verwachting tot de grootste opbrengsten zou leiden – de beste aanbeveling van de onderzoekers – werd slechts door 1% van de boeren gebruikt; 99% paste de technologie aan. De variatie in opbrengst van de proeven was groot, en gemiddeld leverden de proefpercelen niet meer op dan de eigen velden met klimbonen van boeren. De behaalde opbrengsten beïnvloedden echter niet of boeren de klimbonen ook in het volgende seizoen verbouwden. Huishoudenskenmerken waren wel van invloed op de verbouw van klimbonen: armere boeren teelden de bonen vaker maar gebruikten minder van de beste aanbevelingen, en mannen gebruikten doorgaans meer van de landbouwpraktijken dan vrouwen. Het planten van klimbonen door armere boeren resulteerde in aanpassingen zoals de verbouw van klimbonen zonder kunstmest en met minder en kortere bonenstaken. Andere relaties met huishoudenskenmerken waren inconsistent, en boeren veranderden de landbouwpraktijken van seizoen tot seizoen. Dit toonde aan dat de adoptie van technologieën bestaande uit meerdere componenten een proces is dat moeilijk is te vatten door het monitoren van het gebruik van die technologie door boeren op één enkel tijdstip. Tevens bemoeilijken, net als in Hoofdstuk 3, de inconsistenties in het gebruik van landbouwpraktijken door boeren en in de relaties met verklarende factoren het formuleren van aanbevelingen over de geschiktheid van technologieën voor verschillende typen boeren.

Mogelijkheden, beperkingen en compromissen voor de verbouw van klimbonen op bedrijfsniveau werden beschouwd in *Hoofdstuk 5*. Dit hoofdstuk richtte zich alleen op de oostelijke hooglanden, omdat klimbonen nieuw waren voor de meeste boeren in dit gebied, terwijl boeren in het zuidwesten al langer aan klimbonen gewend bleken te zijn. Voor boeren in de oostelijke hooglanden stelden we hun huidige voedselzelfvoorziening, inkomen, investeringskosten en arbeidsinzet vast, en evalueerden, ex ante, de effecten op deze indicatoren van vier opties voor de verbouw van klimbonen. Input voor deze evaluatie waren een gedetailleerde karakterisering van 16 boerenbedrijven van vier verschillende types, en de resultaten van de proeven met klimbonen op boerenvelden uit Hoofdstuk 4. Over het algemeen verbeterden klimbonen voedselzelfvoorziening en inkomen, maar ze vereisten vaak hogere investeringskosten en altijd meer arbeidsinzet dan in de huidige bedrijfssamenstelling. De kleine boerderijen van de armste boeren beperkten de mogelijkheden voor de integratie van klimbonen vergeleken met grotere bedrijven. Bovendien zijn armere boeren waarschijnlijk niet in staat om de benodigde investeringen te doen. De analyse werd vertaald in een eenvoudig te gebruiken model om een participatieve analyse van de resultaten met de vier typen boeren mogelijk te maken en hun perspectieven en besluitvorming te begrijpen. Uit de discussies bleek een recente stijging van de marktprijzen voor klimbonen, die resulteerde in een groeiende belangstelling voor hun teelt. Om de teelt van klimbonen in het gebied te verbeteren, moeten grotere hoeveelheden zaad worden geproduceerd en beschikbaar gemaakt worden door het versterken van boerencoöperaties en verbeterde opslagmogelijkheden.

Elk van de vier onderzoekshoofdstukken in dit proefschrift ging uit van de veronderstelling dat het mogelijk zou zijn om specifieke opties voor de verbouw van peulvruchten aan te bevelen voor verschillende typen boeren, met verschillen tussen boeren voornamelijk gerelateerd aan agro-ecologische en socio-economische variabelen. In ieder hoofdstuk werden we echter geconfronteerd met variabiliteit en inconsistenties in relaties met verklarende factoren die de formulering van aanbevelingen over de geschiktheid van technologieën voor verschillende typen boeren bemoeilijkten. We concludeerden daarom dat typologieën van boerenbedrijven relevant waren om de diversiteit van boeren te beschrijven, maar ongeschikt waren om de prestaties, voorkeur, adoptie of effecten van technologieën te voorspellen. Een pakket met opties, toegesneden op lokale omstandigheden, werd als nuttiger beoordeeld dan nauw gespecificeerde technologieën voor vooraf gedefinieerde boerderijtypen.

Het betrekken van de perspectieven van gebruikers bij het ontwerp van technologieën leverde inzichten op zoals het belang van mengteelt van klimbonen en de beperkingen voor de toepassing van alternatieve methoden voor het ondersteunen van bonen met staken. Hoewel het belang van dergelijke perspectieven wordt erkend, waren er compromissen tussen de mate van detail en de benodigde tijdsinvestering voor het verkrijgen van deze perspectieven. De integratie van evaluaties van demonstratieproeven door boeren in het herontwerp van technologieën, evenals hun feedback op het testen van technologieën op hun eigen veld – uitgesplitst naar verschillende typen boeren – werden beschouwd als twee componenten van dit onderzoek die relatief eenvoudig toepasbaar zijn in andere grootschalige onderzoek-voor-ontwikkelingsprojecten. Bovendien kunnen resultaten die zijn ontwikkeld na (intensieve) interacties met een beperkte groep boeren worden gebruikt voor opschaling naar grotere aantallen begunstigden. Het is daarom niet nodig om in elk nieuw gebied een intensief, gezamenlijk ontwerpproces toe te passen. De opties voor armere boeren om de voordelen van peulvruchten te verbeteren waren beperkt in dit proefschrift. Landbouwinnovaties moeten daarom samengaan met institutionele innovatie om van invloed te zijn op het levensonderhoud van arme boeren.

Acknowledgements

I could not have completed this PhD thesis without the support of many people. First of all, I would like to thank Ken Giller, my promotor. You gave me a lot of opportunities within the N2Africa project, including the possibility to conduct my PhD. I truly enjoyed the inspiring and fun discussions we had, both as part of my PhD and during the trips we made together in the beginning of my work for N2Africa. I am also very grateful to Katrien Descheemaeker for being such a pleasant supervisor with always positive, constructive and stimulating feedback. Many thanks to Conny Almekinders for your everlasting enthusiasm and critical social science reflections, and to Peter Ebanyat for your valuable support during the field work in Uganda and your well thought through comments.

Linus Franke started as supervisor in the beginning of my PhD. I have learned a lot from you about agronomy and data analysis, and enjoyed our many discussions in Wageningen and in the field about my research, our work in N2Africa and many other things. I am grateful to Joost van Heerwaarden for your support on the statistics and stimulating discussions about research design and data collection. I also gained a lot of inspiration and conceptual insights from Bernard Vanlauwe.

At PPS, I've shared offices, lunches, coffees, drinks and jokes with many people: Renske, Ilse, Lotte W., Lotte K., Wytze, Greta, Jannike, Gatien, João, Guillaume, Edouard, Leonard, Marieke, Madeleine, Jairos, Wilson, Godfrey, Jiska, Hanna, Eva, Anne, Wim, Juliana, Linda, Sheida, Argyris, Bob, Christiaan, Jochem, Pytrik, Gerrie, Maja, Martin, Bert R., Bert J. and Alex-Jan. Especially Renske and Ilse, my paranymphs, were always available for a chat on the ups and downs of doing a PhD. Thanks all for the nice breaks from work! And thanks to Charlotte, Linda and Ria for their administrative and logistical help, always provided with a smile.

I owe a lot to N2Africa field liaison officers John Ssekamwa and Justine Onyinge. Their help in the field and in data collection has been invaluable, and I enjoyed your company and laughter during my stays in Kapchorwa and Kabale. Former MSc students Eva Thuijsman, Laurie van Reemst, Jan Hüskens, Ezakiel Muranda, Florence Ajio and Bugingo Collins have been of great help in data collection and in sharing their insights through reports and discussions – I really appreciated your enthusiasm about the topic. A special thanks to Wytze Marinus for collecting additional data during and after your study, for your thorough analyses and MSc thesis, and for the fun and interesting discussions in the field.

I would also like to thank Anthony Epel and Connetie Ayesiga for their support in data collection and valuable insights in the functioning of N2Africa in Uganda. Thanks to field assistants Fred, Patrick N., Patrick K., Francis, Innocent and Rosira for the introduction and guidance in the different districts, and for continuing data collection in my absence. Thank you Gertrude, for being a great translator and for adding a special flavour to my last visit to Kapchorwa with drinks, dance and laughter. I would also like to thank Tumusiime Topista for allowing me to use the picture of her hard work in the beautiful surroundings of Kanungu on the cover of my thesis.

Many thanks to Piet van Asten for providing all the necessary support at the IITA office and inviting me along for dinner, drinks and other fun activities. I enjoyed my stays at the IITA student house in Kampala with Mariëtte, Mandy, Gil, Theresa and many others – although staying in Kampala often meant that I had to wait for something, you made this waiting time really well-spent! Racheal, Millie and Beatrice, thanks for all the logistical support, and Paul, David, Johnson and Joshua – thanks for driving me safely all the time.

Within the N2Africa project, I would like to express my gratitude to Esther Chinedu and Mahamadi Dianda for answering all my questions about the chapter on soybean Nigeria and their help in pushing for soil sample analyses. Freddy Baijukya, thanks for hosting me in Tanzania and providing the necessary support when we were considering including Tanzania as part of my research. A pity that this did not work out. And thanks to all other colleagues in N2Africa for making this such a great project to work in.

Finally, I would like to thank my parents, Gert Ronner and Hetty Vredegoor, for your unconditional love and support and everlasting faith in me. Thanks to my brother Jelte and sister Agnes for being there. Maurice, thanks for your confidence, your good sense of humour and for stimulating and supporting me in the decisions that I have made to get here. Max, thank you for bringing us so much joy and making me realize what is really important in life.

About the author

Esther Ronner was born on 16 October 1981 in Groningen, The Netherlands. She grew up in Deventer, where she attended high school. After studying Dutch Language and Literature in Nijmegen for 6 months, she moved to Utrecht where she studied Human Geography at the University of Utrecht. She specialized in International Development Studies. She conducted fieldwork for her MSc thesis in Mali on livelihood strategies and sustainable agriculture in smallholder irrigation systems. She also conducted an internship at the United Nations Conference on Trade and Development in Geneva, Switzerland.

Esther graduated in 2006, and worked for almost three years at ECORYS, an economic research and consultancy company. Her work focused on regional and urban development in the Netherlands. She realized, however, that her passion really lied in working on agriculture in developing countries. To improve on her technical and agronomic skills, she decided to conduct another MSc study at Wageningen University: International Land and Water Management, specializing in irrigation and water management. This study included a minor in plant sciences. For her MSc thesis, she analysed the effects of conservation agriculture on the seasonal water balance in Kenya.

Since her graduation in 2011, Esther works at the Plant Production Systems Group of Wageningen University. Initially, she was involved in the extension of the N2Africa project, focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in Africa, to Ethiopia, Tanzania and Uganda. Her work extended to the analysis of data collected in the project, as well as the project’s impact assessment after the first (2010-2013) and second (2014-2018) phase. From 2012 onwards, she combined the work in N2Africa with her PhD in the same project.

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PE&RC Training and Education Statement

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

Review of literature (4.5 ECTS)

Improved legume technologies for African smallholder farmers: baskets of options for different types of farmers (2015)

Writing of project proposal (4.5 ECTS)

Impact of sustainable intensification of agricultural production through legume technologies on smallholder farming systems in Sub-Saharan Africa (2012)

Post-graduate courses (5.7 ECTS)

- Mixed linear models; PE&RC (2013)
- Multivariate analysis; PE&RC (2013)
- Farming systems and rural livelihoods: vulnerability and adaptation; PE&RC (2013)
- Introduction to R for statistical analysis; PE&RC (2015)

Invited review of (unpublished) journal manuscript (4 ECTS)

- Field Crops Research: production risks and profitability of soybean on smallholder farms in sub-Saharan Africa (2015)
- Experimental Agriculture: integrating scientific and local soils knowledge to examine options by context interactions for P addition to legumes in the Andes (2015)
- Agricultural Systems: stepwise frameworks for understanding the utilisation of sustainable intensification technologies in Africa (2016)
- Plant and Soil: genotypic differences in symbiotic nitrogen fixation ability and grain yield of climbing bean (2017)

Deficiency, refresh, brush-up courses (2 ECTS)

Systems analysis, simulation and systems management; PPS (2012)

Competence strengthening / skills courses (3 ECTS)

- Working in projects, time management, project management; ECORYS (2007-2009)
- Interpersonal communication; ECORYS (2008)
- Techniques for writing and presenting a scientific paper; WGS (2013)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- PE&RC Weekend (2012)
- PE&RC CoS-SIS seminar: science for impact (2014)
- Wageningen PhD symposium (2017)

Discussion groups / local seminars / other scientific meetings (7.5 ECTS)

- N2Africa meetings (2012-2017)
- Attending meetings of SIAS discussion group (2013-2016)
- Member of SIAS board (2014-2015)

International symposia, workshops and conferences (6.3 ECTS)

- ISFM Conference (2012)
- Global Food Security conference (2013)
- Farming Systems Design conference (2015)

Lecturing / Supervision of practicals / tutorials (2.7 ECTS)

- Analysing sustainability of farming systems (2015)
- Interdisciplinary approaches in communication, health and life sciences (2015, 2016)
- Analysing sustainability of farming systems (2017)

Supervision of MSc students (6 ECTS)

- Understanding drivers behind the implementation and adaptation of improved climbing bean (*Phaseolus Vulgaris* L.) technologies by smallholder farmers in Kapchorwa district, Eastern Uganda
- Opportunities and constraints for climbing bean (*Phaseolus vulgaris* L.) cultivation by smallholder farmers in the Ugandan highlands: Developing a ‘basket of options’

Financial support

The research described in this thesis was financially supported by the Bill & Melinda Gates Foundation through the project N2Africa: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (www.N2Africa.org).

Financial support from Wageningen University for printing of this thesis is gratefully acknowledged.

Cover design by Bert Vredegoor (www.bertvredegoor.nl)

Printed by: Gildeprint