Opportunities and constraints for climbing bean (*Phaseolus vulgaris* L.) cultivation by smallholder farmers in the Ugandan highlands

Developing a 'basket of options'

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MSc thesis
Plant Production Systems – N2Africa

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Table of contents

Summary

Uganda has a tremendous annual population growth (3.36 %), resulting in an increasing demand for food. The eastern and south-western highlands are among the most densely populated areas in Uganda, resulting in a need for increasing crop yields ha^{-1}. Due to the higher altitudes there is a temperate climate, suitable for climbing bean (*Phaseolus vulgaris* L.). Climbing bean can have yields 2-3 times higher than bush bean and is therefore a promising option to increase bean yields in the eastern and south-western highlands. The research-in-development project N2Africa, of which this study was part, aims to “put nitrogen fixation to work for smallholder farmers in Africa” by integrating and improving grain legume technologies in farming systems of sub-Saharan Africa (SSA). Uptake of (improved) legume technologies might be determined by the production objectives of different farm types present within an area and their market access. The main objectives of this study therefore were to describe and explain the opportunities and constraints for climbing bean cultivation by smallholder farmers in an area with good market access (Chema, eastern highlands) and in an area with poor market access (Mpungu, south-western highlands). This information was then used to explore possible options that could be used to design ‘best-fit’ climbing bean cropping technologies.

A rapid farm characterization (RFC) survey was conducted in the eastern (75 households) and south-western (50 households) highlands to construct farm typologies for Chema and Mpungu. For each farm type in both areas, four households were randomly selected (32 in total) for a detailed farm characterization (DFC). Four consecutive surveys were conducted to retrieve socio-economic characteristics of these households and perceived opportunities and constraints for climbing bean cultivation. Furthermore, all fields cultivated by each household (season 2014A, 89 in Chema, 149 in Mpungu) were measured and cultivated crops, crop management, input use, and yields were assessed. For climbing bean fields also stake length, stake density and plant density were assessed. Soil samples were taken for chemical analysis in 3-4 fields per household. Best current management practices of climbing bean, which resulted in higher yields, were used to estimate possible yield increases with current available cropping technologies.

Farm typologies were similar for both areas. Ranges for specific characteristics per farm type differed between Chema and Mpungu, while production orientation and most important source of income were the same for farm types 1-3 in both areas. Farm types (FT1) and 2 (FT2) included the poorest households. FT1 mainly depended on off-farm labour for (cash) income and FT2 typically engaged in some small business while both produced mainly for home consumption. Farm Type 3 (FT3) mainly focused on agricultural production for household income and cultivated more land than FT1 and FT2. farm type 4 (FT4) was only present in Mpungu and engaged in commercial farming (tea, coffee, timber) and cultivated considerable more land than FT3. Farm type 5 (FT5) was only present in Chema and obtained most income from a salaried job. Farm produce was mostly for home consumption. Differences in market access, land availability and job opportunities seemed the most important reasons why FT4 only occurred in Mpungu and FT5 only occurred in Chema.

Typical cropping systems in Chema were the banana-coffee gardens that were intercropped with bush and climbing bean. Banana gardens were also common in Mpungu. The number of crops cultivated was related to farm type and in Chema ‘better-off’ farm types focused more on maize/bush bean cultivation in the lowlands than ‘poorer’ farm types. Tea was an important cash crop in Mpungu and only cultivated by ‘better-off’ farm types, ‘poorer’ farm types cultivated more climbing bean, sweet potato and cassava. ‘Poorer’ farm types cultivated less and smaller fields than ‘better-off’ farm types (FT3, FT4 and FT5) in both areas. Both organic and inorganic fertilizer-use were related to farm type, where FT1 used no or very little fertilizers. In-organic fertilizers in Mpungu were only applied to tea fields and only used by FT3 and FT4. Fields were poorest in Mpungu. In particular pH, available P and K were below critical levels in Mpungu, resulting in poor soils for agricultural production. Available P was below critical levels in Chema whereas other soil fertility indicators were rather good for agricultural production. Soil fertility indicators were most favourable in banana(-coffee) fields in both areas, which were also the fields closest to the homestead.

Climbing bean was cultivated by 66% of the households in Chema and by nearly all households in Mpungu. 80% of the households cultivating climbing bean in Chema, cultivated it on a 'smaller area', whereby a 'smaller area' was defined as a field with <30% climbing bean in intercropping or an area of <30 m^2. 'Bigger area' climbing bean fields had >30% climbing bean and an area >30 m^2. Climbing bean yields were corrected for percentage intercropping to compare yields between fields. Average climbing bean grain yields for 'smaller area' fields in Chema were 1019 kg ha^{-1} and 2113 kg ha^{-1} for 'bigger area' fields. Climbing bean yields were considerably lower in Mpungu, 811 kg ha^{-1}, while management was comparable with 'bigger area' fields in Chema. Poor soil fertility and pests (mole rats and birds) were most important constraints for climbing bean productivity in Mpungu. In Chema, management factors like sowing density and, to a lesser extent, staking density, were related to climbing bean grain yield. Lower yields were related to high clay contents in Chema, which might be a result of erosion. Crop yields were not related to farm types in both areas, although 'bigger area' fields were more common for 'better-off' farm types in Chema. Only absolute cultivated area of climbing bean was related to farm type in Mpungu, while percentage of the farm cultivated with climbing bean was higher for 'poorer' farm types.

'Smaller area' fields in Chema showed poorer management than 'bigger area' fields, which was one of the reasons why 'smaller area' fields resulted in lower yields and higher cost than 'bigger area' fields. Climbing bean and bush bean gave comparable grain yields at <50% intercropping, making bush bean currently a more favourable option for intercropping systems in Chema. Options for improved crop management (based on currently used best management) however, was estimated to increase climbing bean yields up to 60% for 'smaller area' fields. Profitability of climbing bean intercropping could therefore be considerably increased with these 'best-fit' options. For 'bigger area' fields, using current best management options for all fields, yield increases of 30% were estimated in Chema. Yield improvements through the use of currently used best management options were estimated to be very limited in Mpungu due to the overriding constraints of poor soil fertility and pests. 'Best-fit' options to increase (climbing bean) yields in Mpungu could only be successful if inputs like fertilizers (P, K and lime) would be included in these options and if these would become more available and accessible. Furthermore, options should be included to reduce pest damage of mole rats.

Incorporating options for 'smaller area' climbing bean cultivation in N2Africa's agronomic and demonstration trials could be a way to further develop 'bet-fit' options for the biggest group of households cultivating climbing bean in Chema, which include the 'poorer' farm types. Developing options for the most efficient fertilizer-use on field and farm level could be further steps to increase climbing bean productivity in Mpungu. The recommended planting density for climbing bean by N2Africa (80,000 plants ha^{-1}) might be reconsidered since highest yields in farmers' fields were obtained at 200,000 and 300,000 plants ha^{-1} in Chema and Mpungu respectively.

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1 Introduction

The annual estimated population growth rate of Uganda was 3.36% in 2005-2010 (UN-DESA, 2012), putting Uganda among the top 10 countries in population growth in the world (CIA, 2014). This enormous population growth results in major challenges for Uganda to keep up food supply with demand. The eastern and south-western highlands are amongst the areas with highest population density in Uganda which is mainly due to their high potential agricultural productivity and a result of the often favourable biophysical conditions (e.g. rainfall, soil fertility) (FAO, 2006). Leaving the land fallow for fertility regeneration is often abandoned due to increasing population and decreasing farm sizes (Nyende and Delve, 2004). Additionally, erosion and low external inputs of nutrients together threaten sustainability of agricultural production (NEMA, 2004). This calls for intensified cropping technologies that can increase production, while maintaining natural resources for future generations.

The eastern and south-western highlands of Uganda are characterized by smallholder farming in the montane agro-ecological zone, using banana (matooke, *Musa* spp., AAA-EA) as staple crop. Other important crops are common bean (*Phaseolus vulgaris* L.), maize (*Zea mays* L.), sweet potato (*Ipomoea batatas* (L.) Lam), cassava (*Manihot esculenta* Crantz) and Irish potato (*Solanum tuberosum* L.) (FAO, 2006). An option to contribute to sustainable intensification of these cropping systems can be the introduction of improved common bean technologies. Common bean is able to increase the available nitrogen (N) in the cropping system though N_2-fixation (Giller, 2001) and beans can be a nutritious food source as they contain higher concentrations of proteins and micronutrients than staples crops like maize for instance (De Jager, 2013). Common bean varieties can be distinguished by two types, varieties that have a climbing habit (referred to hereafter as 'climbing bean') and varieties that are supported by their own stem (referred to hereafter as 'bush bean') (van Schoonhoven and Corrales, 1987). Climbing bean varieties can have yields that are 2-3 times higher than bush bean varieties. These higher yields make climbing bean a crop with high potential for uptake in densely populated highland areas with ongoing land fragmentation as found in eastern and central Africa (Sperling and Muyaneza, 1995).

A pathway towards 'best-fit' technologies

Adoption of technologies like new cropping systems that can improve yields and food security (e.g. climbing bean) is often less successful and different than expected or aimed for (Ojiem et al., 2006). For example, 'poorer' households often do not benefit or benefit less, while the 'better-off' benefit most as they dare to take the risk or because they have better possibilities to invest in new technologies. New technologies can thus be biophysically and economically feasible and still not adopted due to specific constraints for certain groups within society. Oijem et al. (2006) described this as the socio-ecological niche in which a new technology should fit in order to be successful. Describing such a socio-ecological niche asks for a thorough understanding of the local farming systems (Giller et al., 2011).

The research-in-development project N2Africa aims to provide a 'basket of options' with 'best-fit' legume technologies in order to 'put nitrogen fixation to work for smallholder farmers in Africa' (Giller et al., 2013). The research on how to develop such a 'basket of options', which includes a range of 'best-fit' technologies that can fit for specific groups of farming households (including the 'poorer') within a certain context however, has remained limited. The main aim of this study therefore was to describe a pathway to develop such 'best-fit' options for climbing bean technologies. Firstly, the current farming systems in an area in the eastern highlands and an area in the south-western highlands of Uganda were described through the use of farm typologies and detailed farm characterization. Cropping systems in the eastern and south-western highlands contained complex intercropping systems which have been scarcely studied and are typical for the African highlands. Alternative methods to analyse these complex intercropping systems were therefore sought as common agronomic methods failed to do so. Secondly, this information about the current farming systems was used to explain the current climbing bean cropping systems and thirdly, technology options were explored that can be used to design ‘best-fit’ technologies for different types of climbing bean farmers in the eastern and south-western highlands.

This pathway for developing ‘best-fit’ options, that was used for climbing bean in this case, could also be used for other crops, in other areas. Findings on what can be ‘best-fit’ climbing bean options in the eastern and south-western highlands of Uganda could also be used for other African highlands areas that have for example similar farm types or a similar soil fertility.

2 Theoretical framework

Developing 'best-fit' options

Development of technologies in general can go through many different pathways and is most often not 'linear' or rational (e.g. a logical sequence of steps as designed by the researcher). Research for example can be biased or can overlook certain options and thereby exclude possibly favourable options for the user. This is often because researchers do not consider the specific needs and objectives of the user for using such a new technology, as researchers themselves may have different objectives than the users or come from another culture. The 'better' option might eventually however, be taken into account by other researchers or users themselves (Pinch and Bijker, 1987). 'Linear' approaches in development and promotion of (legume) cropping technologies have led to many failures in promoting these technologies as they did not take into account the specific needs of its users (Ojiem et al., 2006; Vanlauwe and Giller, 2006). It might be hard or impossible to take into account all users when developing a technology. Therefore, technology development should go through an iterative process, whereby lessons learned on the 'goodness of fit' from the earlier introduction of a technology should be incorporated to develop eventually a 'basket of options' with 'best-fit' technologies that suit specific groups of farming households (Sumberg, 2005; Giller et al., 2008; Giller et al., 2013).

Technology development could go through three stages, whereby the 'goodness of fit' increases in each stage. These three stages might also be seen as historical developments, where at first there were mainly 'blanket recommendations' that for instance recommended to apply a certain fixed dose of fertilizer to maize, for a whole country. A second improved stage can be 'best-bet' options, which can be based on literature research and expert knowledge. 'Best-bet' options could for example be a range of best varieties and a recommended fertilizers application rate that fits for the biophysical conditions in a specific area. The third group of options are 'best-fit' options. 'Best-fit' options use for instance the evaluations of 'best-bets' to improve these and to come to options that can fit for specific groups of farming households (i.e. 'poorer' or 'better-off') and/or for specific soil fertility levels (i.e. poor, medium and fertile fields). To come to one final 'best-fit' technology however, might be impossible as smallholder farming systems in sub-Saharan Africa (SSA) are 'moving targets' that change over time (Giller et al., 2011). The goal should therefore be to come to a 'basket of options' that can be offered to farmers, with 'best-fit' options that can be improved and changed over time and fit for different types of farming households in a certain area (Ojiem et al., 2006; Giller et al., 2011). By developing a 'basket of options', it is aimed to find a middle ground in offering options that are neither too specific (i.e. per farmer, per field), nor too broad (i.e 'silver bullets', 'blanket recommendations') (Giller et al., 2011).

The DEED-cycle as described by Giller et al. (2008) captures such an iterative process that can be used to incorporate the lessons learned from earlier designed and used ('best-bet' or 'best-fit') technologies. It identifies four phases of development: from Describe (D), to Explain (E), to Explore (E), to Design (D), where the process starts over again at Describe. Stakeholders are involved in each of these four phases to come to a design of a technology that fits within current farming systems. Several cycles of the DEED sequence are used within the N2Africa project to come towards a 'basket of options' that includes 'best-fit' technologies
(Giller, 2013). In a first DEED-cycle 'best-bet' technologies are identified when the project starts to work in a target area (e.g. Baijukya et al. (2010)). These are then demonstrated and tested in agronomic and demonstration trials. Evaluating these 'best-bet' technologies in consultation with farmers and other local stakeholders results in a second cycle where current processes are explained, improvements are explored and improved technologies are designed. It is aimed to finally come to 'best-fit' technologies that can be offered to farmers by repeating the DEED-cycle several times (Giller et al., 2013; N2Africa, 2013).

N2Africa had started to demonstrate 'best-bet' climbing bean cropping technologies in the eastern highlands when this study took place and was about to start demonstrations in the south-western highlands the following season. This study engaged in the first three steps of a second DEED-cycle, firstly to describe and explain the current farming systems in the eastern and south-western highlands of Uganda. Secondly, building on the knowledge from the first two steps, options were explored to access improved climbing bean technologies that could fit for specific groups of farming households and be used as input for designing 'best-fit' technologies.

Farming systems analysis

Farm typologies aim to capture heterogeneity in farming systems in an area to such an extent that biggest differences in local diversity are captured within the different farm types (Giller et al., 2011; Alvarez et al., 2014). Farm typologies can thereby be used to characterize the socio-economic, institutional, and agro-ecological context of farming systems in which a new technology has to fit and how this differs for specific groups of farming households. A number of reports have shown for instance that there is a difference in resource use and farm management between resource poor and 'better-off' farmers in an area. Farm typologies typically group households in 3-5 different farm types according to difference in for example resource endowment, production orientation, off-farm income, and/or other indicators that are relevant for the purpose of research (Tittonell et al., 2010; Giller et al., 2011).

Farm typologies have for example been used to describe cropping systems and crops cultivated by different farm types (Tittonell et al., 2005b; Zingore et al., 2007a; Reckling, 2011; Van den Brand, 2011), to describe and explain yields and fertility gradients within farms, villages and regions (Tittonell et al., 2005a; Tittonell et al., 2005b; Tittonell et al., 2007; Zingore et al., 2007a; Ebanyat, 2009; Tittonell et al., 2010; Tittonell et al., 2013), and to conduct risk analyses of new legume cropping systems (Kamanga et al., 2010). Farm typologies thus allow characterizing the specific constraints and opportunities of the different farm types as related to their socio-economic, institutional, and agro-ecological environment. Hence, they can also serve as a basis to explore and design technologies that are targeted to specific farm types (Giller et al., 2011; Alvarez et al., 2014; Vanlauwe et al., 2014a), as was for instance shown by Franke et al. (2014) for legume technologies in Malawi.

By analysing different farm types as part of farming systems, also different scales than the farm level itself (e.g. the village or market level) can be considered. Market access and opportunities for generating cash income are for instance often intertwined and strongly influence farming systems and therefore also the opportunities for new technologies. Casual off-farm labour is often the only opportunity for 'poorer' farm types to generate enough income as crop productions is too low for this group of households (Tittonell et al., 2005a; Tittonell et al., 2007). Off-farm labour often competes with crop management on the own farm for 'poorer' farm types (Tittonell et al., 2007; Tittonell et al., 2009). For 'better-off' households who have salaried jobs (of which its availability is often also influenced by market access), off-farm income can be used to acquire inputs for farming (Tittonell et al., 2009). Market access also influences the availability of inputs and the opportunities to sell farm produce. In return, selling high value farm produce to the markets can be an important way to acquire cash that can be invested in farm inputs (De Ridder et al., 2004; Tittonell et al., 2009).

Sustainable intensification through legume cultivation

Sustainably increasing crop yields (sustainable agricultural intensification) in SSA is needed to keep track with the enormous population growth (SDSN, 2013; The Montpellier Panel, 2013; Vanlauwe et al., 2014a). Nutrients are the most limiting factor in crop production for most areas of SSA (Penning de Vries and Djiteye, 1982; Breman et al., 2001; Fermont et al., 2008). Of nutrients, N is generally most limiting (Giller, 2001). Organic and inorganic fertilizer can be sources of nutrients but are often not available or too expensive (not accessible) for smallholder farmers in SSA (Tittonell and Giller, 2013). Legumes however, can be a 'free' source of nitrogen as they are able to form a symbiosis with rhizobia through which they fix nitrogen from the air. N_2-fixation therefore, makes legumes not solely dependent on soil N and often results in a net contribution of N to the soil N pool (Giller and Cadisch, 1995). Legumes are therefore seen as a key option for sustainable intensification of smallholder farming systems of SSA (Giller and Cadisch, 1995; Peoples et al., 1995; Giller, 2001). Legumes are also often part of options for Integrated Soil Fertility Management (ISFM) to sustainably increase soil fertility and thereby crop yields (Vanlauwe et al., 2010; Tittonell and Giller, 2013). Like the introduction of many other technologies however, adoption of legume technologies in SSA has often been disappointing (Giller, 2001; Snapp and Silim, 2002), as adoption depends on many more factors than beneficial effects on soil fertility alone (Ojiem et al., 2006).

When analysing the uptake of legume cropping technologies, grain legumes like groundnut, soya bean, cowpea and common bean are often preferred over green manures for (Sanginga, 2003). A higher uptake of grain legumes is mainly due to their direct benefits (the grain). Direct (financial) benefits are often valued more by farmers than possible contribution to soil fertility, which are often prioritised by researchers (Giller and Cadisch, 1995; Ojiem et al., 2006; Vanlauwe and Giller, 2006).

Adoption of legume technologies is often different per farm type or wealth class. Van den Brand (2011) showed in Malawi, where maize is the main staple crop, that legumes are cultivated less by the 'poorer' and more by the 'better-off' and middle class farm types. In Rwanda however, where beans are a staple crop, adoption of new climbing bean varieties seemed to be higher for 'poorer' households (Sperling and Muyaneza, 1995). In Uganda uptake of improved bush bean varieties was found to be most profitable for middle-class farmers as they had labour and resources available to cultivate these varieties (David et al., 2000). For Malawi it was suggested that uptake of new legume technologies also depends on farm type (Van den Brand, 2011). Kamanga et al. (2010) for instance described how yields of legumes were generally lower than maize yields, resulting in a bigger risk for 'poorer' farm types to become food insecure if they cultivated legumes instead of maize, than for 'better-off' farm types. Riskiness is also often a reason why 'poorer' farming households are less likely to take up more profitable options as these options generally require more inputs and therefore result in bigger losses if a crop fails.

Climbing bean

Climbing bean is a grain legume with potentially high (grain) yields and could therefore be used to develop 'best-fit' options for the eastern and south-western highlands of Uganda, where high population densities and declining soil fertility require sustainably intensified cropping systems. Common bean contributes only little to the soil N balance, but does also not extract a lot (Giller and Cadisch, 1995; Reckling, 2011; Ronner and Franke, 2012). Grain yield differs a lot for different types of common bean. The bush bean type in the Ugandan highlands typically has a yield of around 500-1000 kg ha^{-1}, whereas the climbing bean type has yields up to 1500-3000 kg ha^{-1} (NARO, 2012; NaCRRI, 2013). These higher yields of climbing bean can be merely attributed to its higher leaf area index, which enables climbing bean to capture a bigger proportion of the available radiation than bush bean. Climbing bean is therefore a nutritious food source that, if residues are managed well (Reckling, 2011), does not further reduce soil N stocks and in comparison with bush bean, gives higher yields.

Climbing bean however, requires different management practices and inputs than bush bean. It is less prone to root rot but often has more problems with pests like birds for example. Climbing bean also needs staking. Stakes can be long branches (2-3 m) of *Grevillea* or *Eucalyptus* trees or for example *Pennisetum* stalks. In Rwanda it was found that stake length was related to yield, while number of stakes m^{-2} was related to household type. The 'better-off' had more stakes per m^{-2} and higher yields than the 'poorer households (Klapwijk, 2011; Reckling, 2011). Previous research also showed that staking was a limiting factor for the adoption of climbing bean technologies in the eastern highlands of Uganda (Ronner, personal communication). Taking stakes from natural areas in the eastern highlands can also affect forest growth and can thereby damage the natural ecosystems (Sassen and Sheil, 2013). Staking and staking methods are therefore a crucial aspect in the success of climbing bean technologies.

Climbing bean also needs more nutrients than bush bean as it produces more biomass. The soil nutrient base needs to be replenished by organic and/or inorganic fertilizer inputs in order to keep sustainable cropping systems (Stoorvogel et al., 1993; Vanlauwe et al., 2010). Both soil fertility and fertilizer use (organic and inorganic) however, are often related to farm type, where ‘poorer’ farm types have poorer fields and have more difficulty to access fertilizers than ‘better-off’ farm types (Tittonell and Giller, 2013). As ‘poorer’ farm types might also find it more difficult to acquire stakes or stakes of good quality, the potential success of climbing bean technologies might be limited for ‘poorer’ farmers in the Ugandan highlands. To develop ‘best-fit’ technologies that could improve yields and soil fertility for the ‘poorer’ farm types in Uganda, in particular in poor market access areas, might therefore be critical. Developing these options for ‘poorer’ farming households however, is also most important, as it is these households that are most food insecure, find it hardest to sustain a living, and generally comprise the largest group of farmers.

3 Research questions and hypotheses

The first objective of this study was to assess the opportunities and constraints for climbing bean cultivation within current farming systems of the eastern and south-western highlands of Uganda. The second objective was to explore possible options for improved climbing bean cropping technologies that can fit for different groups of households, (e.g. farm types) within these farming systems. Describing and assessing these options contributes to filling a 'basket of options' that could sustainably increase the production of smallholder farming systems in the eastern and south-western highlands of Uganda. The following questions were defined to come to a description of the current farming systems, current climbing bean cultivation and options to increase current climbing bean productivity. Each sub-question is followed by a bullet-point which gives the hypothesis for this sub-question. Since the answers to question three depend on the answers found in questions one and two, no hypotheses were formulated for question three.

1. What characterises the current farming systems in the eastern and south-western highlands of Uganda?
    a. What are the differences between the eastern and south-western highlands in terms of socio-ecological factors?
        - Both areas differ in market access.
        - Better market access in the eastern highlands results in more commercial crops, more modern varieties and a higher use of inputs than in the south-western highlands.
        - The eastern and south-western highlands do not differ in soil fertility.
    b. How can farmers in the eastern and south-western highlands be categorised in a farm typology?
        - Despite the differences in environment, diversity within farming systems of the eastern and south-western highlands can be captured in one typology using characteristics similar to those of Tittonell et al. (2005a); Tittonell et al. (2010).
    c. What characterises the current cropping systems of different farm types in the eastern and south-western highlands?
        - 'Better-off' farm types use more intensified cropping technologies and are better able to invest in new technologies (i.e. climbing bean cultivation or fertilizer use), while 'poorer' farmers cultivate more staple crops and have less opportunities to change to more intensified cropping technologies.

2. How can current climbing bean cultivation in the eastern and south-western highlands of Uganda be characterized and what are opportunities and constraints to increase current climbing bean productivity?
    a. How does the cultivated area of climbing bean differ among farm types and between the eastern and south-western highlands?
        - Climbing bean is cultivated more by the 'better-off' than the 'poorer' farm types.
        - Climbing bean is cultivated more in eastern highlands than in the south-western highlands.
    b. Which factors affect climbing bean yields and how does this differ between farm types and between the eastern and south-western highlands of Uganda?
        - Soil fertility indicators are generally lower for 'poorer' farmers than for 'better-off' farmers.
        - Input use (i.e. stakes, fertilizers) is generally higher for 'better-off' farmers than for 'poorer' farmers.
        - Climbing bean yields of 'poorer' farm types are smaller than those of the 'better-off' farmers.

- Climbing bean productivity is higher in the eastern highlands than the south-western highlands.

c. What is the availability and accessibility of inputs (e.g. labour, cash, seed, stakes, fertilizers), needed for climbing bean cultivation in both areas, for different farm types?
   - Stakes and labour are the most limiting factor for both areas.
   - 'Better-off' households invest more cash in agriculture.
   - Labour availability depends on farm type and is higher for farm types focusing on agricultural production.

3. What options increase climbing bean productivity for different types of smallholder farmers in the eastern and south-western highlands?
   a. What options can be identified to increase climbing bean productivity within the current cropping systems of the eastern and south-western highlands?
   b. How would these options affect yields and profitability of climbing bean cultivation?

4 Methodology

By selecting the eastern and south-western highlands, the two major areas with potential for climbing bean cultivation in Uganda were covered. Two districts were selected, Kapchorwa in the eastern highlands for its better market access and Kanungu in the south-western highlands for its presumed poorer market access. A specific research site was selected in the N2Africa action sites within these districts. In Kapchorwa, the middle-belt of Chema sub-county was selected for its good connection to markets (along the Kapchorwa-Mbale road) and its current climbing bean cultivation. Chema middle-belt was reported as an area with intermediate climbing bean adoption when compared with surrounding areas and had seen increasing adoption in the past years (Ronner 2014, personal communication). This intermediate stage of current climbing bean adoption in Chema middle-belt was selected to assess possible differences between households currently cultivating climbing bean and households not cultivating climbing bean. Chema middle-belt is referred to hereafter as Chema or Chema sub-county. Within Kanungu, The N2Africa action site with least market access was selected, Mpungu sub-county (Fig. 2). To cover an area with a similar size as Chema middle-belt, Hamurwa village was selected as research site within Mpungu. Hamurwa village is referred to as Mpungu or Mpungu sub-county hereafter. Although little was known about climbing bean cultivation in Mpungu beforehand, it was assumed that due to poor market access climbing bean would be less prevalent in Mpungu than in Chema.

The N2Africa project had started with its first demonstrations in Chema in the 2014A season, the same season as when this study took place and was about to start the following season in Mpungu. Further steps within the project entail co-construction sessions as a part of Esther Ronner's PhD research in which farmers, extension agents and researchers work together to come to improved climbing bean technologies. Her PhD-research also monitors the evaluation of demonstrations with farmer groups to further develop 'best-fit' climbing bean cropping technologies. By doing research with farmers, within farmers' fields, both biophysical and socio-economic constraints specific to these areas and specific to these farm types, are taken into account when developing options.

In the following section general characteristics of both research sites are described. Then the two types of surveys used in this study are discussed. The first survey conducted was the rapid farm characterization (RFC) survey, which was meant to capture a larger number of households to get an overview of the current farming systems in both areas and to construct a farm typology. The second was the detailed farm characterization (DFC) survey. The DFC is discussed in the third section of this chapter. Data analysis is discussed in the fourth section and exploring possible 'best-fit options is discussed in section five.

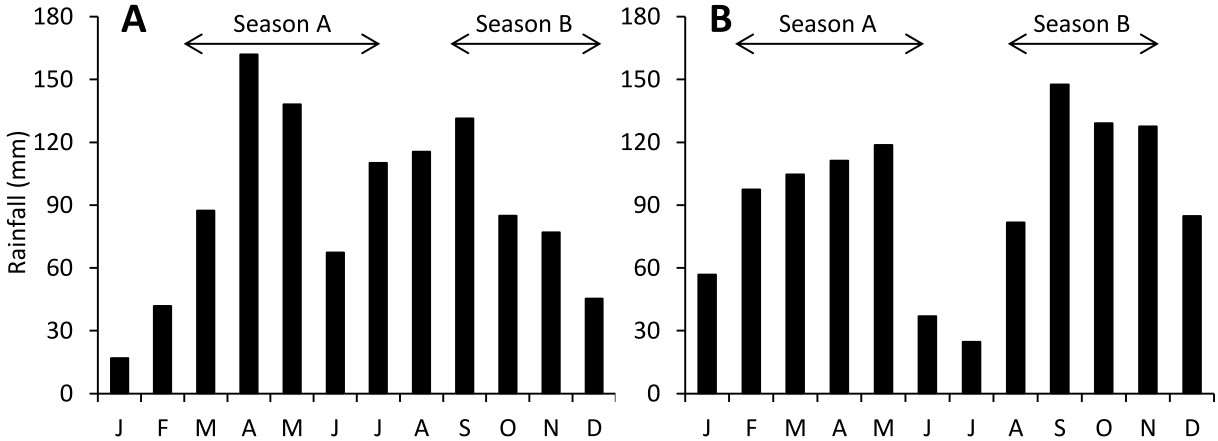


Fig. 1. Monthly average rainfall (2007-2013) for Kapchorwa (A) and Mpungu (B) (FAO/GIEWS, 2014a). Arrows indicate the different cropping seasons (FAO/GIEWS, 2014b).

4.1 General characteristics Chema and Mpungu

Chema (Kapchorwa district) and Mpungu (Kanungu district) have a bimodal cropping season and receive similar total annual rainfall (Fig. 1, Table 1). Field research took place in 2014, season A. Season A in Chema is the main cropping season, whereas in Mpungu season B is seen as the main cropping season. Season A starts one month earlier in Mpungu (February) than in Chema (March). Soils in Chema were of volcanic orgin whereas in Mpungu they had most likely developed from pre-Cambrian deposits. Population densities for both areas seemed similar according to the 2006 national population surveys (UBOS, 2006a; UBOS, 2006b), local population densities however tend to show a large variability (Ronner and Giller, 2012). From observations it seemed therefore that Chema had a denser population than Mpungu.

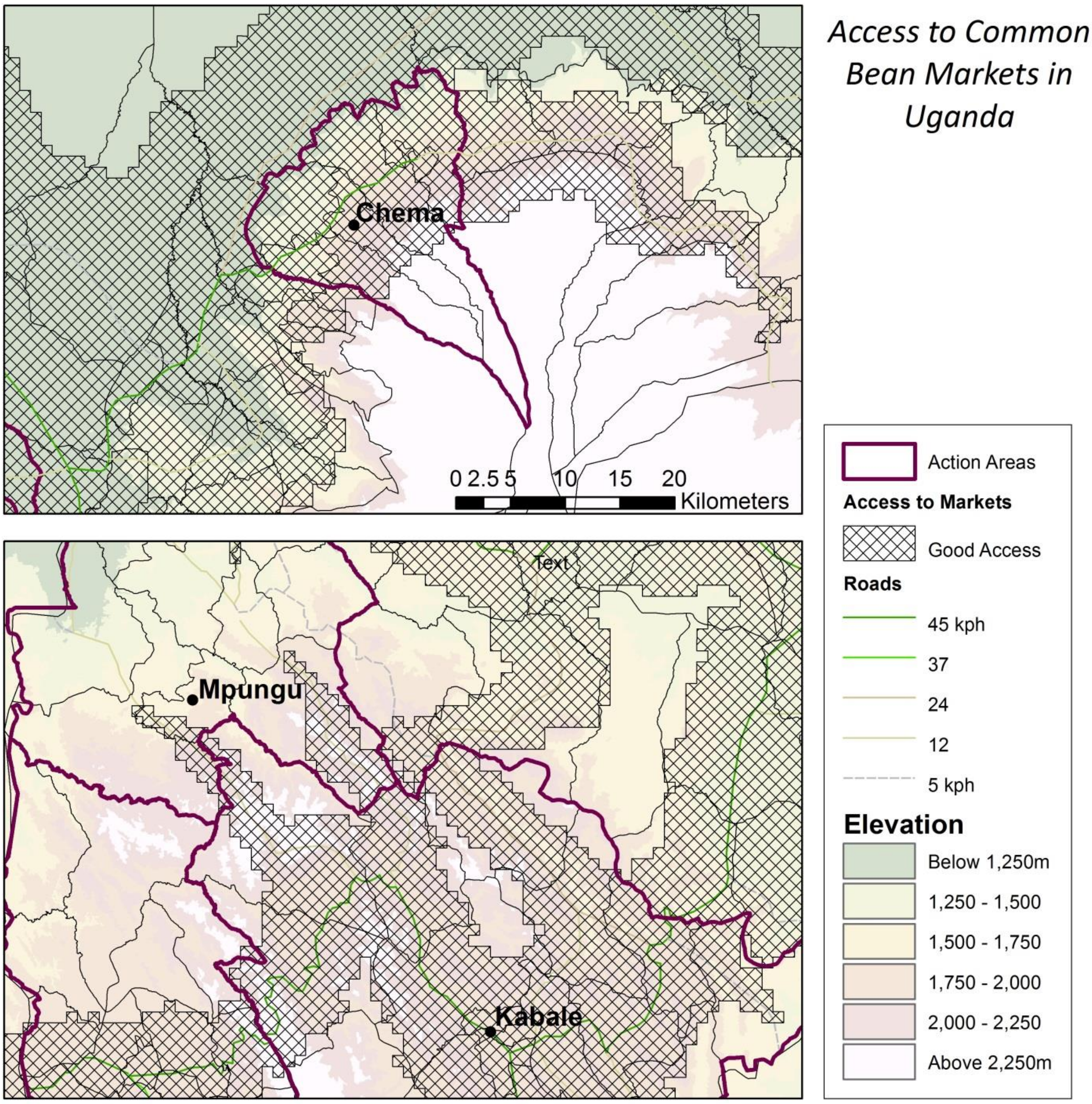


Fig. 2. Access to common bean markets for Chema and Mpungu, based on Farrow (2014).

Table 1. Agro-ecological and socio economic characteristics of the two research areas.

		Kapchorwa (Chema)	Kanungu (Mpungu)
Cropping seasons[1]	A	March-July	February-June
	B	September-December	August-November
Total annual rainfall[2]		1070 mm	1121 mm
Population density[3]		72-638 people km^2	132-302 people km^2
		Chema sub-county: 226 people km^2	Mpungu sub county: 222 people km^2
Soil type[4]		Luvisols	Acrisols
Distance to main market		1-1.5 hours	2.5-3 hours
		Tarmac road	Dirt road

[1](FAO/GIEWS, 2014b), [2](FAO/GIEWS, 2014a), [3](UBOS, 2006a; UBOS, 2006b), [4](FAO, 1995; ISRIC, 2014)

4.2 Rapid farm characterization

Two different surveys were used for the RFC. In Chema a modified N2Africa 'Meta-data and farm typology survey' was used and conducted within this research in April 2014 and is referred to as RFC survey hereafter. For Mpungu the dataset of the N2Africa baseline survey was used, which was conducted in May 2014 and is also referred to as RFC survey hereafter. The RFC-survey in both areas contained questions on a range of household characteristics: household size and composition, schooling level, livestock owned, arable land owned, production orientation, frequency of hiring labour, food sufficiency, sources of income, valuable goods owned, crops cultivated and crop management. The different approaches for developing farm typologies for both areas are discussed below. All households interviewed for the RFC survey were grouped into farm types, which were used to select households for the DFC at a later stage. Data from the RFC and interviews with resource persons were used to describe the general characteristics and history of both areas. The bigger number of households interviewed for the RFC survey and its information on crop cultivation also allowed for a more general analysis of current climbing bean cultivation in both areas.

Developing typologies – Chema

The RFC-survey in Chema was held with 75 households. This area contained four parishes and in total 23 villages. To ensure a well spread sample over the area, stratified random sampling was used, selecting for each parish at least one village, five villages in total. Villages (the lowest administrative unit) contained 19-74 households. 15 households were randomly selected per village using the pen-twist method (starting in front of the house of the village chairman).

A farm typology was developed based on these 75 questionnaires. Households with similar characteristics were grouped, starting for instance by considering cultivated area after which it was assessed whether other characteristics like production orientation and most important source of income also differed for these groups. This process of sorting and rearranging groups of households with similar characteristics was repeated until four to five farm types were distinguished.

Farm typologies in this study were inspired by farm typologies developed by Tittonell et al. (2005a) for western Kenya and Tittonell et al. (2010) for western Kenya and eastern Uganda. Resource persons (the chairman of a local cooperation, well informed farmers, an extension officer) in Chema were interviewed at the time of farm typology development. Interviews with resource persons were used to get a broader overview of the history and farming systems of the area. Information from these resource persons was used to triangulate whether all farm types as present in Chema (including for example the poorest and the richest) were included in the farm typology.

Developing typologies – Mpungu

In Kanungu district, the N2Africa baseline survey data-set (50 households) was used to compose a draft farm typology in a similar manner as was done in Chema. The N2Africa baseline survey was conducted in two sub-counties of Kanungu district, Rutenga and Mpungu, and per sub-county one village was selected. The communities in both villages were asked to gather during a meeting, at which a list of all people present was composed. 25 households were randomly selected from this list for the baseline survey. This selection method however, might have resulted in excluding specific types of households. 'Poorer' households might for example be too occupied, 'better-off' households on the other side, might not be interested in this type of meetings and therefore also not attend. Furthermore, a smaller number of households was sampled per location in Kanungu than in Chema, which might have resulted in overlooking less common groups of households. To capture this possible bias or shortcoming in sampling of households, first a draft farm typology was constructed based on all RFC-surveys in Kanungu. The draft farm typology was discussed with different resource persons (sub-county chief, sub-county chairman, contact person Africa 2000 Network) within Mpungu sub-county to ensure that it represented all households within Hamurwa village. Based on these discussions and additional RFC surveys with household types that were not included in the draft typology, a final farm typology was composed. Since there were considerable differences between Mpungu and Rutenga, only the results of the RFC survey in Mpungu are presented in the results section (25 N2Africa baseline surveys + 4 RFC surveys).

4.3 Detailed farm characterization

Per farm type four households were randomly selected in both localities, interviewing 16 households in both areas, 32 in total. In Chema households were stratified for climbing bean cultivation. There were farmers cultivating bigger areas of climbing bean (often in sole cropping), and farmers cultivating only small areas of climbing bean (mostly intercropping). Cultivating a larger area of climbing bean can be seen as a higher rate of adoption of climbing bean cultivation than cultivating a smaller area of climbing bean. Hence, to consider the differences, a distinction between the two groups was made in Chema. Per farm type, two households were selected that cultivated climbing bean on a 'bigger area' and two who cultivated climbing bean on a 'smaller area'. Households cultivating a 'bigger area' of climbing bean were defined as those who cultivated climbing bean in intercropping with >30% climbing bean (or sole cropping) and who were cultivating at least an area of 30 m^2 climbing bean. Households with a 'smaller area' of climbing bean were defined as those who cultivated less than 30 m^2 climbing bean, were intercropping with <30% climbing bean, or who cultivated no climbing bean at all. Households in Mpungu were not stratified for type of climbing bean cultivation since nearly all households cultivated climbing bean, using similar technologies.

The DFC consisted of four consecutive surveys using structured interviews, taking in total 5-8 hours (depending on farm size and travel time from the homestead to the fields). A detailed overview of the surveys used for the DFC can be found in Table 6. Survey 1 focused on confirming information from the RFC-survey, for example on farm type and climbing bean cultivation. Furthermore a farm map was drawn including all cultivated fields and crops cultivated. When farm type and climbing bean cultivation was confirmed, households were asked to record climbing bean yields for all fields under climbing bean cultivation (also 'smaller area' climbing bean fields). Sacks were handed out per field to collect and store dry grains for later measurement. A cup and a recording sheet were handed out to measure and record fresh bean consumption.

During survey 2 all cultivated fields of 2014A were visited. Questions were asked on historical management and geographical characteristics (e.g. slope, observed erosion) and crop management, like percentage intercropping (estimated percentage area per crop) were assessed. Fields were measured using a handheld GPS device (Garmin eTrex 10, error of measurement: 3-4 m). Waypoints were taken for all corners delineating the field boundary. Waypoints were later connected to form 'routes' and converted to polygons using the software package ExpertGPS 4.89 (TopoGrafix 2014) to calculate area per field. If fields had a side with a length less than 20 m, this was measured by making steps of 1 m. Soil samples were taken from 3-4 fields per farm (mixed sub-sample of 10-15 samples per field, taken in w-shape, 0-20 cm depth). To enable comparison of soil sample results between households, it was aimed to take samples in fields that contained common crops in both areas. If present, soil samples of at least one climbing bean field per household were taken. For fields containing climbing bean, stake density, stake length and number of plants per stake were assessed using a quadrat of 2 by 2 m (4 m^2). In 'bigger area' climbing bean fields (Chema and Mpungu), two quadrants were assessed to capture variability within the field. In 'smaller area' fields in Chema, only one quadrat was assessed.

Survey 3 contained questions on household income and expenditure and on climbing bean cultivation (opportunities and constraints). Similar questions on perceived opportunities and constraints for climbing bean cultivation were asked to households cultivating climbing bean as well as to households not cultivating climbing bean.

Survey 4 was conducted at the end of the cropping season 2014A to assess observed yields. For climbing bean, collected (air-dried) beans were weighed and the fresh bean consumption sheet was collected. If possible, at this or earlier surveys, a cup of fresh beans was weighed. For all other annual crops of 2014A, farmers were asked to estimate the yield per field. Since maize of the first season (A) in Chema is harvested half way the second season, this could not be assessed. Instead, farmers were asked to estimate their 2013 maize yields, which are presented separately. Annual banana yields were assessed by asking for normal weekly yields and by asking for which periods of the year this was higher or lower and what these differences were.

Table 2. Content of the four surveys as conducted for the DFC in Chema and Mpungu.

Survey 1	Survey 2	Survey 3	Survey 4
- Household composition - Schooling level - Labour availability - Farm map - Field inventory - Crop management (e.g. planting date, variety, rotation) - Importance of crops - Cropping calendar and labour inputs per activity - Change in cultivated crops - History of climbing bean cultivation - Handing out climbing bean measuring sheets	Field visit, per field: - Field size - Distance to homestead - Land ownership - Geographical characteristics - Farmers' soil fertility class - Confirm crops - % Intercropping - Type of field preparation - Sowing arrangement - (in)Organic fertilizer use - Other input use Soil samples of selected fields Climbing bean fields: - Staking date - Staking method - Source of stakes - Pest and disease pressure - Stake and planting density - Stake length	Income and expenditure 2013: - Crop and livestock income - Off-farm income - Other sources of income - Farm inputs purchased - Expenditure on hired labour - Regular household expenditure - Price variation important crops - Livestock keeping, feed and manure Climbing bean: - Opportunities and constraints - Input use - Perceived labour input - Residue management - Knowledge on staking methods - Availability of stakes	Yield assessment: - Measuring climbing bean yield - Farmer estimated yields all other crops - Pest and disease pressure - Proportion sold

4.4 Data analysis

Farmers' estimated and measured cultivated area. Measured cultivated area during the DFC for households belonging to farm type 1 (FT1), farm type 2 (FT2) and farm type 3 (FT3) in Mpungu was about three to four times smaller than the farmers' estimated cultivated area in the RFC, although there was a reasonable relation between farmers' estimated and measured cultivated area (R^2=0.51, Fig. 3). The slope of the relations was similar to the relation between the local unit for land area, 'inchingo', and acres. Resource persons estimated that one acre contained four 'inchingo'. Therefore, it was assumed that during the N2Africa baseline survey, local units were not taken into account and field sizes mentioned by farmers were noted as acres instead of 'inchingo'. Field sizes derived from the N2Africa baseline survey were therefore all divided by four to correct for local units. Corrected field sizes were used for further analysis.

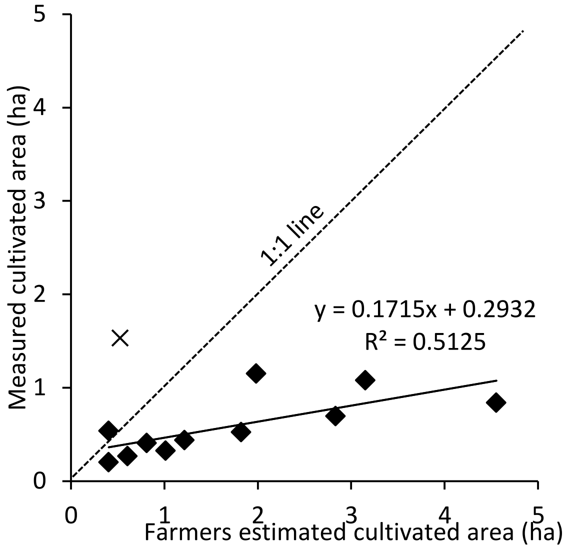


Fig. 3. Farmers' estimated cultivated area (season 2014B) and measured cultivated area (season 2013B) for the 12 households from the DFC belonging to FT1, FT2 and FT3 in Mpungu.

Soil sample analysis

Soil samples were prepared for chemical analysis (air dried, sieved and ground) at Makerere University soil lab 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. To assess consistency of the soil sample analysis, 10 reference sub-samples (originating from one, thoroughly mixed, sample) were added. Reference samples were given similar coding as the samples taken in Chema and Mpungu and analysed together with the samples from Chema and Mpungu. Variation between results was found to be acceptable (CV<0.10) for pH, organic carbon (OC), available P, Ca, Mg, K and texture (Annex I). Total N showed considerable variation (CV = 0.23) and results for total N of soils samples from farmers' fields in Chema and Mpungu analysed with care.

Table 3. Weights of local units as measured on local markets in Mpungu (Hamurwa and Kalambi) and conversion ratios for un-threshed maize and millet cobs as measured from interviewed farmers.

Crop		Local unit	Weight (kg)
Bush bean	Threshed	Cup	0.49
Irish potato		Basin	19
Irish potato		Basket	12.5
Maize	Threshed	Cup	0.46
Maize	Threshed	Basin	10.5
Maize	Threshed	Basket	19.5
Maize	Un-threshed	Bag	46
Millet	Threshed	Cup	0.48
Millet	Threshed	Bag	110
Sorghum	Threshed	Cup	0.39
Sorghum	Threshed	Bag	110
Sorghum	Threshed	Basin	9
Sorghum	Threshed	Basket	17

Other factors used for analysing yields		
1 Umchebbe	:	6 Cups
1 Endebbe	:	8 Umchebbe
HI of maize cobs 80%		
HI of millet cobs 70%		

Yields and local units

In Chema, kilogram was commonly used as unit to measure and report yields. For bigger quantities however, the number of bags was reported. Different resource persons indicated that bags were filled to 100 kg. Bags were therefore assumed to be 100 kg. In Mpungu, bigger quantities were also reported in bags. Smaller amounts, however were reported in local units. Local markets were visited and the weight of local units were measured per commodity (Table 3), which was later used to calculate farmers reported yields ha^{-1} (using field size as measured in Survey 2). Measuring grains was mostly done using a cup in Mpungu. Bigger quantities were expressed in umchebbe or endebbe, which were a number of cups (Table 3).

Intercropping percentage and cultivated area per crop

To calculate the area cultivated with a certain crop per field, field size was multiplied with the percentage intercropping of that crop. To calculate the total cultivated area of a crop, per farm, the former were summed for all fields. The percentage of the farm cultivated with a crop was then also derived.

The possible relation between percentage intercropping of a certain crop and its yield, was considered before further analysis. Most intercropping systems consisted of combinations of annual and perennial crops. Estimating annual yields of perennial crops proved to be difficult, resulting in unreliable estimates. Therefore, no land equivalent ratios could be used to compare yields between plots. Furthermore, comparing annual yields of perennials with yields obtained in season A and/or B from annuals in land equivalent ratios might be arbitrary as well. Instead, annual yields were corrected if a relation was found between percentage intercropping (Fig. 4A) and yields and if correcting these yields for percentage intercropping resulted in realistic yields (similar to or lower than yields of that crop in sole cropping, Fig. 4B). For example, a percentage intercropping of 20% would result in a yield reduction of 80% and hence yield would be divided by 0.2 to convert to sole crop yields. Uncorrected yields were used for further analysis if no relation was found between percentage intercropping and yield.

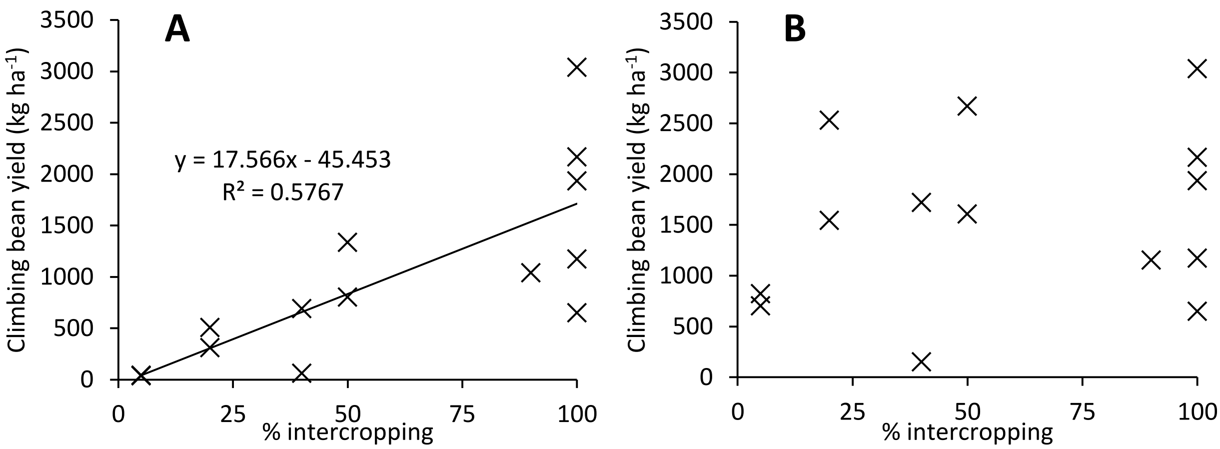


Fig. 4. Uncorrected climbing bean grain yields in Chema as related to percentage intercropping in a field ($P < 0.001$) (A) and climbing bean grain yields corrected for percentage intercropping (B).

Distance to the homestead

The correlation between measured distance between the homestead and a field and the farmer-estimated travel time seemed reasonable in both Chema (R^2=0.74) and Mpungu (R^2=0.49, Fig. 5). Slopes were undulating too steep in both areas and there were virtually no straight paths from a homestead to a field, resulting in travel time being considerably different from the measured distance 'as the crow flies'. For this reason, farmer-estimated travel time in minutes was used for further analysis.

Income and expenditure
The yearly household balance considered household income and expenditure for 2013. Income only considered cash income from selling farm produce (farm revenue) and off-farm income or other monetary income (off-farm revenue). Produce consumed by the household for instance, was not converted to cash income. The same applied for household expenditure, where for example family labour was not considered a cost and only hired labour inputs for crop cultivation was considered as a cost. Regular household costs were assessed by asking for household expenditure during an average week (e.g. food, soap) and during an average year or month (e.g. clothes, cooking utensils).

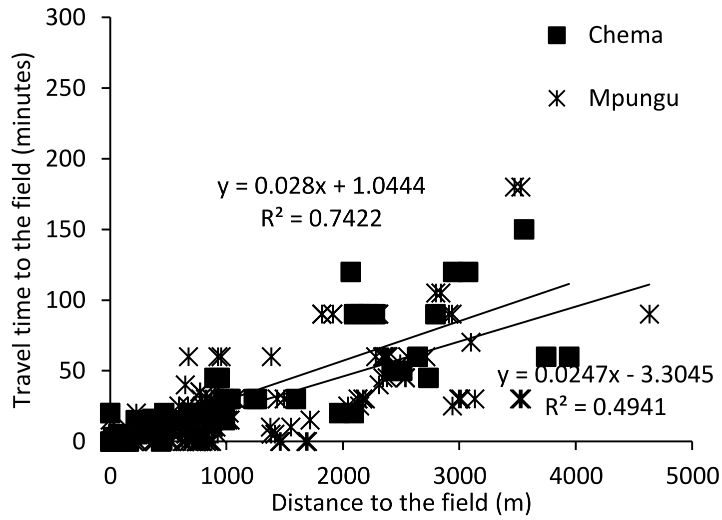


Fig. 5. Farmer-estimated travel time from the homestead to the field (minutes) as related to the distance to the field 'as the crow flies' (meters, based on the distance between coordinates as measured at the homestead and as measured at the field).

Labour demand and availability
Timing of cropping activities in an average year and the labour demand per cropping activity was investigated in Survey 1, for the three most important crops per household and, if not part of these three crops, climbing bean. Labour availability was assessed by asking per household member whether they took part in farm work and for which months they were available to do this farm work. Labour availability was compared with timing of cropping activities to assess labour availability and labour demand for, for instance, climbing bean cropping activities.

Statistical analysis
Linear regression analysis was conducted to explore the possible relations between yield and other factors like farm type, walking distance to the homestead or pest and disease pressure for instance. A correlation matrix was used to assess interrelationships between factors. Where found, interactions between factors were described. Relations were mainly used to triangulate and support findings from other parts of this study (e.g. important constraints reported by farmers, soil sample analysis). For stronger conclusions on factors that explain patterns of variability, more advanced statistics (i.e. generalized linear mixed models) would be needed, which was however not within the scope of this study.

4.5 Exploring options

Current available options
The regression analysis between yield and explanatory variables was used to identify options that could lead to higher yields through the use of best management currently already used by some farmers. Since these options were already used within the farming systems of Chema and Mpungu, they could fit within these systems and it was explored how the 'goodness of fit' would differ for different farm types. Yield estimates were made for the combination of these currently improved management practices, these were then further explored through budget analysis as described in the following section.

To put current farmers' yields and possible improved yields into perspective, they were compared with climbing bean yields as obtained in N2Africa demonstration fields for single staking treatments (similar staking method as currently practiced by farmers). Single staking treatments included treatments with and without fertilizers (manure and triple super phosphate (TSP)) and with local (cv. Kabale) and improved varieties (cv. NABE 12C and NABE 26C). Demonstrations with comparable agro-ecological conditions, close to or within Chema (Chema middle, Chema upper and Tegeres upper) were considered for comparison. For Mpungu, no yield data from demonstrations was available yet , so yield data of 2013B agronomy trials in neighbouring Kabale district were used to compare with farmers' yields in 2014A. Season B however, is the longer cropping season and Kabale is approximately 40 km from Mpungu ('as the crow flies'). Yields in Kabale should therefore only be seen as an indicator for possible yields in Mpungu.

Budget analysis

Partial budget analysis was done to assess current profitability of climbing bean in comparison with profitability of improved management and in comparison with other crops. Since banana is a perennial crop and climbing bean and sorghum was cultivated in both cropping seasons, year round profitability was calculated rather than the profitability of one season. No data was available on differences in yield between both seasons in Chema or Mpungu, hence it was assumed that climbing bean and sorghum had similar yields in season A and B. Maize in Chema was planted once a year at the beginning of the first season and harvested in the second half of the second season. Since maize was not yet harvested at the time of research, farmers reported yields of 2013 were used. Banana yields were recorded in number of bunches harvested per week whereby a distinction was made between parts of the year with higher and lower yields. Similar to the partial budget analysis of climbing bean, labour inputs and prices of inputs and crop yield were based on farmers´ reported labour inputs and prices (Table 4, Annex II). Sowing densities for maize/bush bean and sorghum were based on literature.

Total revenue was calculated by multiplying average yields with grain price. Net revenue was then derived by subtracting the cost of materials (Table 4) from total revenue. Two methods were used to access net returns as related to labour inputs. In the first method, returns to labour (US$ person day^{-1}) were calculated by dividing net revenue by average labour input as obtained in the cropping calendar, to compare returns from crop cultivation with daily wages of casual labourers. Secondly, net revenue (US$ ha^{-1}) was also calculated using labour input as opportunity cost, whereby total labour input was multiplied by the average farmer-reported labour cost per day and subtracted from net revenue as calculated without labour cost. Including labour as opportunity cost assumed that a household could also decide to use its available labour for alternative jobs. Including labour as cost also includes the possible cost for hired labour.

Variability in returns to labour and net revenue were assessed using highest and lowest values for farmers' reported yields and labour inputs. Total percentage variation around the average was also calculated to enable comparison between crops. Highest and lowest crop prices in the past five years (Annex II) were used to assess the effect of price variation on returns to labour.

Table 4. Input cost used for partial budget analysis of different crops in Chema and Mpungu.

Input	Cost		Unit	Data source DFC
	Chema	Mpungu		
CB seed	0.81	0.51	US$ kg^{-1}	Cost in seeds bought 2014
Stakes	0.034	0.006	US$ stake^{-1}	Cost in stakes bought 2014
Labour	1.77	2.11	US$ person^{-1} day^{-1}	Cost labour 2013
BB seed	0.77	-	US$ kg^{-1}	Cost in seeds bought 2014
Maize seed	2.63	-	US$ kg^{-1}	Cost in seeds bought 2014
Sorghum seed	-	0.49	US$ kg^{-1}	Cost in seeds bought 2014

CB, climbing bean; BB, bush bean

5 Results

5.1 Recent trends in food and cash crop cultivation

Food crops

Main food crops in both locations were 'matooke' (or cooking banana, hereafter called 'banana') and beans. It was common for a household to have a banana plantation close to the homestead. In Chema these banana home gardens were commonly intercropped with coffee, bush bean, sometimes climbing bean and some maize or cassava. In Mpungu, home gardens were intercropped with vegetables and coco yam (or taro, *Colocasia esculenta* (L.) Schott, hereafter called 'yam'). Intercropping in banana gardens in Mpungu was strongly discouraged by NAADS extension workers since 1 or 2 years to reduce the spread of banana bacterial wilt. Intercropping the banana home gardens with for example climbing bean was common practice before. Maize was another important food crop in Chema, which was not only grown in Chema middle, but also in fields further away towards the lowlands and intercropped with bush bean. Other important food crops for Mpungu were climbing bean, millet and sorghum.

Typical cash crops and their markets

Coffee was the main cash crop in Chema and mainly sold to an organic processing factory located within the research area. NAADS extension officers mainly focused on improving production of the banana and coffee plantations. According to local resource persons this had resulted in improved plant spacing and the use of more productive varieties of both crops. There were also extension officers employed by the organic coffee factory, who distributed planting material and instructed farmers for example not to use synthetic fertilizers or crop protection agents in their coffee gardens anymore. Since these coffee crops were often part of the home gardens, intercropped crops like banana, bush and climbing bean could also not receive these inputs anymore and only organic fertilizers were allowed.

Since the establishment of the tarmac road from Mbale to Chema in 2002, the travel time to Mbale was reduced to one hour. Mbale town is one of the important agricultural market centres in Uganda and therefore became an important market for produce from Chema. Matooke for example, is collected in Chema by local trading women and transported to Mbale, from where it is sold again to urban centres such as Kampala. Also other agricultural products were sold to Mbale markets, either through local middle women/men or through traders coming from Mbale/Kampala. The new road also resulted in the improved availability of agricultural inputs like seeds, synthetic fertilizers and crop protection agents, resulting in an increased fertilizer use according to the local resource persons.

The typical cash crop in Mpungu was tea. Seedlings, fertilizers, herbicides and spray-pumps were distributed by tea factories to promote tea cultivation. Distribution of fertilizer and herbicides was based on loan schemes, which were paid back by delivering tea to the factory. NAADS extension officers also distributed seedlings and gave advice on tea cultivation in the area. A truck of the local tea factory (one hour from Mpungu) passed daily to collect the fresh picked tea leaves. The focus on tea cultivation however, had resulted in a general food shortage in the region according to local government officials. Food shortage throughout the year however, was not found to be different between Chema and Mpungu in the RFC. Major markets like Kabale town were a 2-3 hours' drive from Mpungu, depending on road conditions. The gravel road passing Mpungu, leading to the Kisoro-Kabale road, was not a major through road and only one pick-up truck daily went to and from Kabale on a daily basis.

Developments in the area

The new road in Chema came along with other developments: an increasing population, new schools, the new coffee factory and the increase of civil service jobs (e.g. NAADS, sub-dividing administrative units) resulted in more employment. This and increased trade of agricultural products also resulted in new businesses like shop keeping and small bars.

In Mpungu there were no such developments yet. The only public institution was a primary school, led by teachers from outside the village. The main cash income was tea cultivation, for which men were said to be responsible. Women were responsible for staple crops like climbing bean, sweet potato, banana and cassava. Earnings were divided in the same manner, where men generally received the cash generated from tea. According to the sub-county chief, alcohol abuse and domestic violence were an important problem in Mpungu.

NAADS officers were still active in both regions at the time of field research. Shortly after however, NAADS and all its extension officers were suspended to be replaced by a new system of extension workers.

5.2 Farm typologies

5.2.1 Constructing farm types

A limited number of characteristics asked for in the RFC was sufficient to construct the farm typologies in Chema and Mpungu. Based on the area of cultivated land, type and number of livestock owned, type of housing, valuable goods owned, production orientation and most important source of income, four farm types were described in Chema (Table 5). Additionally to those characteristics, the type of crops cultivated were also considered in Mpungu, whereas type of housing was not used here (Table 6). Although not used initially for constructing the farm types, additional characteristics are also shown in Table 5 and Table 6 to evaluate the differences for these characteristics as related to farm type.

The draft farm typology for Mpungu, was considerably changed after discussions with the different resource persons. They described a small group of 'better-off' households that owned and cultivated considerably more land than the households considered in the baseline. This group also owned more cattle and cultivated more cash crops like tea, coffee and timber. Following a RFC with the four households that were said to belong to this group of farmers, a new farm type was included in the farm typology, farm type 4 (Table 6). Based on this same discussions and after visiting some of the households of the N2Africa baseline survey, it was found that within Hamurwa village, farm type 5 (FT5) did not exist, meaning that all households gained more than 50% of their income from farm activities. Resource persons in Chema described similar farm types and confirmed that the farm typology covered the different types of households present within Chema middle.

5.2.2 Farm types

Five farm types were used to consider the existing diversity between households in Chema and Mpungu. Farm types 1 and 2 described the poorest households. FT1 received only income from selling little amounts of farm produce and from off-farm labour. FT2 still sold a small part of their farm produce and often had some small business or petty trade. This small business however, accounted for less than 50% of the total household income. For FT3, income from farm produce was more important than that of FT2, off-farm income resulted in no more than 10-30% of the total income of FT3. Agricultural produce was considerably more important for FT3, they typically sold half of it and kept half for home consumption. This focus on agricultural production was even stronger for farm type 4 (FT4), who was selling most or all of its produce. The cultivated area of FT4 was considerably larger than that of all other farm types and crops cultivated were mainly cash crops like tea or coffee. FT4 also engaged in other business like timber cultivation or renting out shops. FT5 was comparable with FT2 or sometimes FT3 when comparing for instance cultivated area or livestock owned. The main source of income of FT5 however, was off-farm income from a salaried job. Salaried jobs included school teachers, local government clerks, pensioners or military personnel and security guards. Farm types 4 and 5 sometimes owned a house with permanent walls, other farm types only had houses with semi-permanent walls and most often iron sheet roofing. Also in valuable goods owned, FT4 and FT5 were comparable.

Apart from the major difference that FT4 was not found in Chema and FT5 not in Mpungu, farm typologies in Chema and Mpungu also differed on the ranges per characteristic (e.g. cultivated area, number of animals owned) that were found per farm type. FT3 in Chema for instance cultivated 1.2-3.6 ha, whereas in Mpungu FT3 estimated to cultivate 0.5-0.8 ha. Production orientation and most important source of income were however similar for FT1, FT2 and FT3 when comparing between Chema and Mpungu, which was the reason for using the same names for FT1, FT2 and FT3 in both areas. Characteristics not used for developing the farm typologies initially (labour hired, age of the household head, education of the household head, food insecurity throughout the year and type of crops cultivated), were also related to farm type and were therefore also part of the farm typology .

Another specific characteristic for Chema was the ownership of lowland fields, which was highest for FT3 and lowest for FT1. Although these fields were further from the homestead (>1 hour walking), due to land scarcity this seemed to be the easiest option for farmers in Chema to expand their cultivated area. In Mpungu, fallow land, natural bush land and timber plantations were owned more by 'better-off' farm types. Households of FT4 estimated for example that these types of land use covered about 2/3 of their total land area owned.

FT2 was the biggest group of households found in both Chema and Mpungu, they accounted for over 40% of the interviewed households (Fig. 7). There were more households belonging to FT1 in Mpungu than in Chema. FT1 and FT2 (together the 'poorer' farm types)therefore together accounted for 80% of the population in Mpungu, while this was only 60% in Chema. Almost one quarter of the population in Chema belonged to FT5. No population data was available for Hamurwa village. From observations however, it was estimated that there were 100-200 households in this area. FT4 was not found among the households in the baseline survey (25 households), which might imply that FT4 represented less than 5% of the total population.

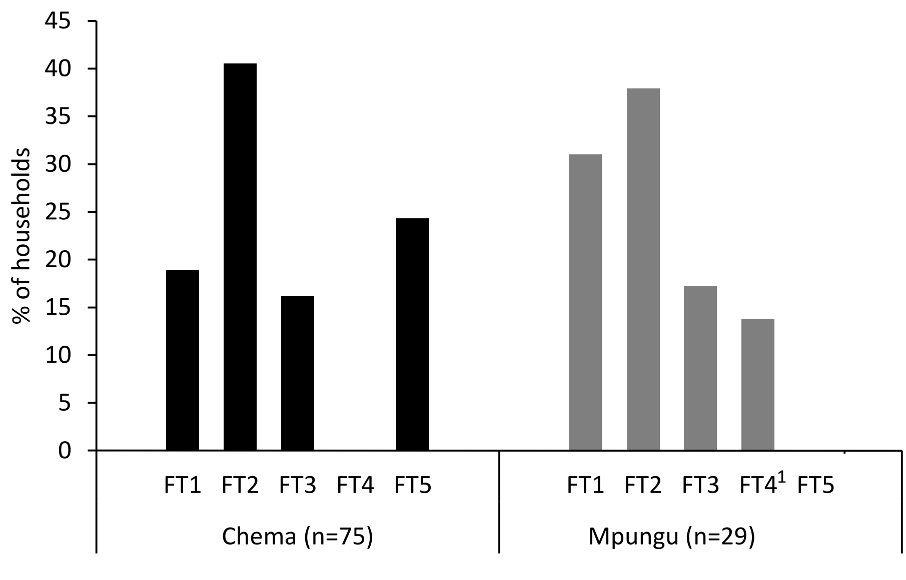


Fig. 6. Distribution of households over the different farm types in Chema and Mpungu as sampled for the RFC.

[1] Households in Mpungu belonging to FT1, FT2 and FT3 (25 in total) were sampled randomly. The four households belonging to FT4 were purposely selected. Omitting these four households results in the following distribution among the farm types: FT1 36%; FT2 44%; FT3 20%, FT4 0% and FT5 0%.

Table 5. Farm typology of Chema based on a rapid farm characterization survey (n=75) in five villages with 15 households randomly sampled per village. Characteristics with a "*" were originally used to construct farm types. Other characteristics were analysed and added to assess possible differences between farm types. Values shown between brackets are minimum and maximum values.

	Characteristics	Farm type 1	Farm type 2	Farm Type 3	Farm type 4[1]	Farm type 5
	n	14	30	12	-	18
Resource endowment	Cultivated land*	<0.4 ha	0.4-1.2 ha	1.2-3.6 ha	-	0.4-2 ha
	Type and number of livestock*	1 local cow[1] or 1 goat, 1-2 chickens	1-3 cows, 1-4 goats, 2-5 chickens	0-8 cows, 0-8 goats, 5-15 chickens	-	0-5 cows, 0-3 goats, 1-15 chickens
	Type of housing*	Thatched or iron sheet roof, semi- permanent walls	Iron sheet roofs, semi-permanent walls	Iron sheet roofs, semi-permanent walls	-	Iron sheet roofs, semi-permanent and permanent walls
	Valuable goods owned*	For example max. one cell phone or radio	Cell phone, radio and/or sofa	Cell phone, radio, sofa and plough	-	Ranging from only cell phone and radio to motor bike or car.
	Households hiring labor during the season	53%	67%	83%	-	94%
	Average age of the household head	39 (20-70)	43 (24-70)	50 (29-74)	-	44 (28-90)
	Education level of the household head	Most primary, part secondary and some none	Most secondary, part primary	Primary and secondary	-	Most secondary, part primary and some university
	Average months of food insecurity	2.3 (2-3)	2.0 (0-3)	1.1 (0-3)	-	2.4 (0-4)
Production orientation and sources of income	Type of crops (2014A)	Banana, coffee, bush bean No lowland fields	Banana, coffee, bush bean 47% has lowland fields	Banana, coffee, bush bean 75% has lowland fields	-	Banana, coffee, bush bean 33% has lowland fields
	Production orientation*	Mostly for home consumption	Most home consumption, part sold	Half sold, half for home consumption	-	Most home consumption, part sold
	Most important source of income*	Labor and little farm produce	Farm produce most important, some other source of income (0-50%)	Farm produce most important, other source <30%	-	Off-farm income most important (>50%)

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

Table 6. Farm typology of Mpungu based on a rapid farm characterization survey with 25 randomly sampled households which resulted in farm types 1-3 and four specifically targeted households, interviewed separately for farm type 4. Attributes with a "*" were originally used to determine farm types. Other attributes were analysed and added to assess possible differences. Values shown between brackets are minimum and maximum values found per farm type.

	Characteristics	Farm type 1	Farm type 2	Farm type 3	Farm type 4	Farm type 5
Resource endowment	Cultivated land*	<0.2 hectare	0.1-0.4 hectare	0.5-0.8 hectare	5-10 hectare[1]	-
	Type and number of livestock*	0-2 goats, 0-2 chickens	0-2 cows, 2-5 goats, 1 pig, 0-7 chickens	0-4 cows, 2-20 goats, 2 pigs, 0-10 chickens	0-16 cows, 5-20 goats, 0-5 chickens	-
	Type of housing	Iron sheet roof, semi-permanent walls	Iron sheet roof, semi-permanent walls	Iron sheet roof, semi-permanent walls	Iron sheet roof, semi-permanent walls	-
	Valuable goods owned*	For example one cell phone and radio	For example cell phone, radio and sofa set	For example cell phone, radio, sofa set and/or bicycle	For example cell phone, radio, sofa set and/or bicycle	-
	Hire farm labor (# households/total per farm type)?	7/9	8/11	5/5	4/4	
	Average age of the household head	42 (21-80)	41 (25-80)	50 (40-58)	69 (57-75)	
	Education level of the household head	None 2/9, Primary 4/9, Secondary 3/9	None 2/11, Primary 5/11, Secondary 4/11	Primary 3/5 Secondary 2/5	Primary 3/4 Post-secondary 1/4	
	Average months of food insecurity	2.9 (0-5)	2.5 (0-5)	1.2 (0-4)	0.5 (0-2)	-
Production orientation and sources of income	Type of crops (2013B)*	3 crops/HH Banana, climbing bean and some millet and sweet potato	2 crops/HH Banana, some climbing bean, maize and millet	5 crops/HH Adding to crops of FT2 maize and some tea	7 crops/HH Adding to crops of FT3 tea, trees and some coffee	-
	Production orientation*	Mostlyfor home consumption	Most home consumption, part sold	Half sold, half for home consumption	Most or all produce sold	-
	Most important source of income*	Farm produce	Farm produce most important, some other source of income (0-50%)	Farm produce, most important, other source <10%	Farm produce 60-80%, trade or other business 10-40%	-

[1] Cultivated land included all fields containing annual crops and perennial crops like banana, coffee and tea. Areas with timber trees and fallow land were not part of this study. Households of FT4 estimated to own 16 to 40 hectares of land in total.

5.3 Detailed characterization of the farming systems

5.3.1 Income and expenditure

All households were found to have a negative total household balance in Chema and Mpungu (Table 7). This negative balance was more negative for 'better-off' farm types and seemed to be more negative in Mpungu than in Chema. FT1-3 in Chema showed a total household balance close to neutral. Off-farm revenue of FT1 was slightly higher than that of FT2 and also higher than off-farm revenue of FT3. The lower off-farm revenue of FT3 might be explained by its focus on agricultural activities whereas FT1 due to its smaller farm size also has to focus on generating off-farm revenue. The total household balance for FT5 was most negative in Chema, which seemed to be mainly caused by its high school cost. Underestimation of off-farm revenue (salaried job) could also be a reason.

Farm revenue and costs for material inputs and labour inputs seemed to be related to farm type in both Chema and Mpungu and increasing from FT1 to FT4. FT1 in Chema had a lower farm revenue and expenditure, resulting in a considerably lower farm net revenue than the other farm types. Costs made for material inputs (fertilizers, seeds, farm tools, veterinary drugs, animal feed) and labour inputs were higher for FT2 and FT3 than for FT1 and FT5, which might be related to their production objectives, where FT1 and FT5 mainly produce for own consumption and FT2 and FT3 also for the market.

FT4 in Mpungu showed a strongly negative total household balance, which was mainly caused by the high estimated cost for labour inputs and regular cost. One household of FT4 particularly influenced the cost for labour inputs, which were US$ 23990 for this household. Leaving out this household would however still result in an average household balance of US$ -3680 (SE 530). Households of FT4 were mainly elderly households with married children that had moved out, mainly depending on hired labour for farm activities.

5.3.2 Labour demand and availability

Labour demand

In both Chema and Mpungu it was estimated that climbing bean needed more person-days ha^{-1} than other crops (Table 8). This was partly because of the need for staking in climbing bean. However, since other management activities (land preparation, weeding) were also estimated to take longer for climbing bean, labour demand for climbing bean could be overestimated or land preparation for climbing bean might be done differently for climbing bean than for other crops. Total time needed for climbing bean cultivation was similar for Chema and Mpungu. Maize/bush bean cultivation in Chema was estimated to have less labour requirements than other crops which might be partly explained by the use of bullock-ploughing for land preparation in lowland maize/bush bean fields.

Climbing bean was planted and harvested almost one month earlier in Mpungu than in Chema. Harvest of fresh pods of climbing bean started about one month before the final harvest. In Chema climbing bean was weeded twice, whereas in Mpungu this was done once. Sorghum was also weeded only once in Mpungu, whereas maize/bush bean in Chema was weeded twice. Also for the banana garden it seems that weeding was done more often in Chema. There might be more labour demand for crop cultivation in Mpungu due to tea cultivation, which could lead to this lower labour input for weeding in Mpungu.

Staking in Chema was done one month after planting (mid to late April) and just before the first weeding. Weeding of maize-bush bean in Chema was done in early May. Staking in Mpungu is also done one month after planting, which is at the same time as weeding of sorghum and sweet potato.

Table 7. Yearly household balance (US$) for the different farm types in Chema and Mpungu based on income and expenditure data of the different households in 2013. SE is shown between parethesis.

Farm type	n	Farm revenue and expenditure			Farm net revenue[2]	Off-farm revenue	Household cost		Total household balance 2013[3]
		Farm revenue	Material inputs	Labour inputs[1]			School cost	Regular cost	
Chema									
1	4	140 (110)	40 (20)	20 (20)	80 (110)	640 (320)	240 (110)	500 (40)	-20 (110)
2	4	1160 (770)	230 (120)	180 (40)	740 (690)	540 (530)	600 (250)	730 (140)	-60 (690)
3	4	1680 (1030)	220 (80)	230 (170)	1230 (990)	120 (120)	350 (180)	1050 (390)	-30 (990)
4	0	-	-	-	-	-	-	-	-
5	4	580 (210)	80 (20)	80 (40)	420 (200)	990 (440)	840 (270)	1010 (230)	-450 (200)
Mpungu									
1	4	50 (10)	0 (0)	140 (50)	-90 (40)	160 (100)	40 (20)	450 (80)	-430 (40)
2	3	250 (50)	110 (60)	210 (110)	-70 (110)	350 (240)	60 (20)	330 (130)	-110 (110)
3	5	1080 (450)	150 (80)	570 (140)	360 (500)	130 (80)	230 (80)	1590 (440)	-1340 (500)
4	4	2760 (1310)	930 (460)	6300 (5310)	-4470 (4460)	610 (60)	870 (650)	4000 (1460)	-7520 (4460)
5	0	-	-	-	-	-	-	-	-

[1] Labour inputs are the costs spent on hired labour
[2] Farm net revenue = farm revenue - (material inputs + labour inputs)
[3] Total household balance = (farm net revenue + off-farm revenue) - (school cost + regular cost)

Table 8. Cropping calendar for the most important crops in Chema and Mpungu. For all crops the average number of person-days ha^{-1} needed during the cropping season were calculated, SE is given between parenthesis. The median for when each cropping activity took place was calculated and is shown with different letters in the cropping calendar.

Crop	n	Person-days ha^{-1}	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Chema											
Banana	15	457 (81)		W			W			W	
Climbing bean	11	705 (164)		LP	S	ST W	W		H		
Maize/BB[1]	11	233 (16)		LP		S	W	W	H[2]		H[3]
Mpungu											
Banana	13	304 (53)	W					W			
Climbing bean	15	665 (106)		LP	S	ST W		H			
Sorghum	6	395 (143)	LP	S		W				H	
Sweet potato	8	432 (112)		LP	S	W			H[4]		

[1] BB=bush bean, [2] Harvesting of bush bean, [3] Harvesting of maize, [4] Harvesting of sweet potato was spread over a longer period of time.
LP=land preparation, S=sowing, ST=staking, W=weeding, H=harvesting. Black represents the cropping season of a crop. Grey represents the time from first until last harvest.

Labour availability
The peaks of labour availability were related to school holidays at the end of a semester (Annex III). School holidays from late-April to mid-May were at the same time of weeding of maize/bush bean and staking and weeding of climbing bean in Chema. In Mpungu these school holidays were almost one month later than staking of climbing bean and weeding of other crops, in Mpungu therefore, there might be less labour available for these activities than in Chema.

On average FT2 seemed to have most labour available (average 3.2 persons working on the farm), whereas FT1 had least labour available in Chema (average 1.8 persons working on the farm). In particular during peak moments of labour avialability FT3 had most labour available in Mpungu (going from 3 (normal) to 6 (peak) persons working on the farm), followed by FT2 and FT4 (both on average 2.9 persons working on the farm). FT1 had least labour available (average 2.4 persons working on the farm). Average labour availability was slightly higher for Mpungu than Chema (averages of 2.4 and 3 persons working on the farm respectively).

5.3.3 Fields and farm size

Farmer estimated cultivated area and measured cultivated area
A reasonable relation between farmer estimated cultivated area and measured cultivated area was found (Chema, R^2=0.69; Mpungu, R^2=0.66). Cultivated area was slightly overestimated in Chema (Fig. 7A). The main reason for this might be that estimated field sizes were mostly rounded to the (upper) nearby multiples of a quarter of an acre. In Mpungu the average cultivated area in the RFC seemed overestimated as well, which for Mpungu might also be caused by the difficulties in translating local units in to SI units. Like in Chema, total number of fields was under estimated in Mpungu, however, due to the much higher overestimated field size, total farm size was still overestimated (Fig. 7B).

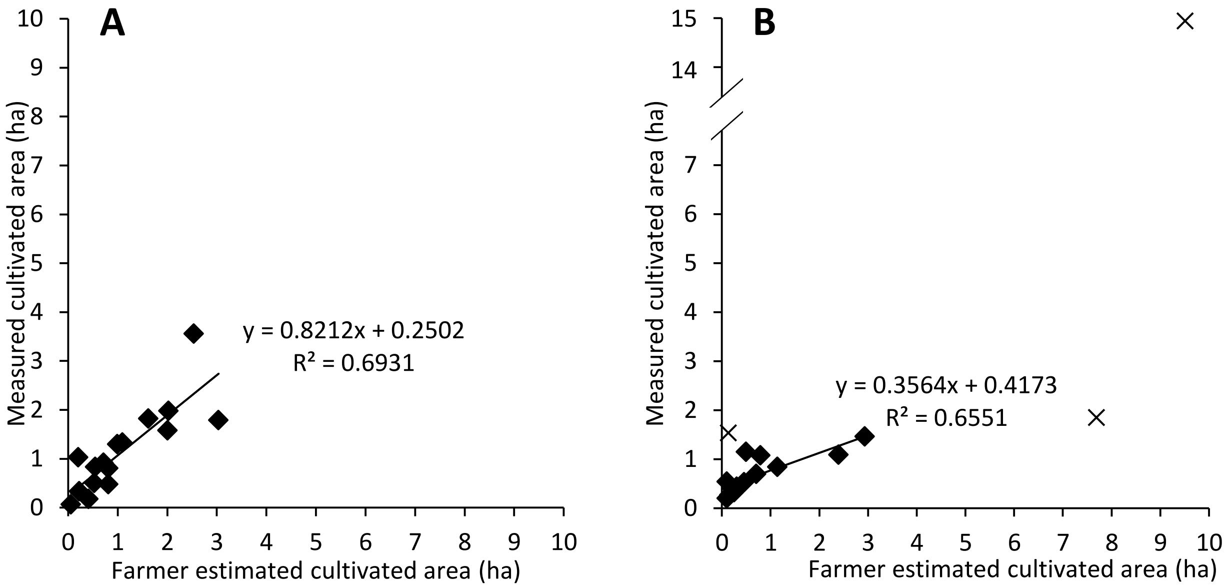


Fig. 7. The relation between farmer estimated cultivated area (RFC) and measured cultivated area (DFC) for Chema (A) and Mpungu (B). Estimated cultivated area in Mpungu was based on estimates for season 2013B and corrected for local units. Estimated cultivated area in Chema and measured cultivated area were both based on 2014A. For Mpungu three values (shown as ×) were left out as outliers, including outliers results in R^2 = 0.63 .

Cultivated area and field size per farm type
FT1 cultivated the smallest area and FT4 the biggest area (Table 9). FT2, FT3 and FT5 showed intermediate values, where FT3 (focusing on agricultural productions) cultivated the biggest area. Cultivated area on average was found to be bigger in Chema than in Mpungu for FT1, FT2 and FT3.

One of the households in Mpungu of FT4 cultivated almost 15 ha. Without this household cultivated area for FT4 would be 1.47. In Chema no household mentioned fallow land, therefore there was no difference between area cultivated and total land area owned. In Mpungu ley farming was common, meaning that especially households of FT3 and FT4 owned more land than the measured cultivated area.

Table 9. Average measured cultivated area (ha) per farm type and land:labour ratios (available labour from the household only) for different farm types in Chema and Mpungu. SE is given on parenthesis.

	Chema		Mpungu	
Farm type	Cultivated area (ha)	Land:labour ratio (ha/person)	Cultivated area (ha)	Land:labour ratio (ha/person)
1	0.52 (0.24)	0.24 (0.11)	0.30 (0.04)	0.12 (0.01)
2	1.00 (0.20)	0.30 (0.13)	0.50 (0.03)	0.20 (0.08)
3	2.22 (0.45)	0.78 (0.14)	1.06 (0.14)	0.27 (0.04)
4	-	-	4.83 (3.37)	1.13 (0.41)
5	0.87 (0.33)	0.30 (0.09)	-	-

Land to labour ratios also differed per farm type and were generally increasing when more land was owned. Only for FT4 in Mpungu, available labour was also lower than for other farm types. This lower available labour for FT4 was related to the age of the household head, meaning that most of the children had moved out and households mainly depended on hired labour as was also seen in the costs made for labour inputs (Table 7). Land to labour ratios were found to be lower for Chema than Mpungu.

The number of plots cultivated per household was highest for FT3 and lowest for FT1 in both areas (Table 10). Average plot size also differed per farm type in both areas, where FT1 cultivated the smallest plots and FT3 and FT4 cultivated the bigest plots (Table 10). Smallest average field sizes were found for households of FT1 in Mpungu, 500 m^2. Field size in Mpungu was on average three times smaller than in Chema. In Mpungu however, the number of cultivated fields was higher than in Chema.

Table 10. Average number of cultivated fields and field size per farm type, assessed at 16 households in both Chema and Mpungu. SE is given between parenthesis.

	Chema		Mpungu	
Farm type	Average # of fields/household	Average field size (ha)[1]	Average # of fields/household	Average field size (ha)[1]
1	3 (0.8)	0.16 (0.045)	6 (0.3)	0.05 (0.009)
2	5 (0.9)	0.18 (0.043)	9 (0.0)	0.06 (0.008)
3	8 (1.5)	0.29 (0.045)	11 (1.0)	0.09 (0.017)
4	-	-	9 (1.2)	0.54 (0.225)
5	5 (1.2)	0.18 (0.041)	-	-

[1] Average field size was first calculated per household, average field size per farm type was calculated from these averages.

5.3.4 Current crop cultivation

Typical cropping systems

62% of the coffee and banana fields in Chema contained bush bean and 24% contained climbing bean. Both climbing and bush beans were planted using a hoe, making a planting hole and putting a number of seeds in each of these holes. In some of the bigger climbing bean fields it seemed that planting holes were arranged in rows, while mostly this seemed random. 73% of the maize fields were intercropped with bush bean, which were either planted in rows in-between the maize rows or within the maize rows.

Banana plantations in Mpungu were most often sole crops, only 25% of the fields contained cocoyam and some were intercropped with vegetables. Climbing bean was intercropped in 29% of the fields with maize. Maize intercropping ranged from 10-20% (area) in these climbing bean fields and was planted at random within the field. Climbing bean was broadcasted over the fields, after which the fields were harrowed using hand-hoes.

Crops cultivated per farm type

In both Chema and Mpungu, the number of crops cultivated seemed to differ per farm type, where the number of crop cultivated per household generally was lowest for FT1 and highest for FT3 (Chema) and FT4 (Mpungu) (Table 11).

Typical home garden crops together (banana, coffee and bush bean) covered a bigger percentage of the cultivated area for households of FT1, than for other farm types in Chema. Since cultivated area differed per farm type, the biggest absolute area of these home garden crops was however cultivated by FT3 and the smallest area by FT1. Maize/bush bean intercropping in Chema was mostly done in the lowlands (1400 MASL). FT3 and FT2 cultivated most land in the lowlands, 63% and 53% of their total cultivated area respectively, whereas for FT1 and FT5 this was both below 1/3 of their total cultivated area. The relative importance (% area) of home garden crops therefore decreased if the percentage area of lowland maize/bush bean increased. As bush bean covered a considerable proportion of the total cultivated area (1/3) for all farm types it showed to be an important crop in Chema. The absolute cultivated area of coffee was biggest for FT3 (and twice as much as for the other three farm types), followed by FT1, FT2 and FT5 respectively. Climbing bean seemed to cover only a smaller part of the cultivated area for all farm types and is discussed in more detail in Chapter 5.3.7 *Current climbing bean cultivation*.

Banana and climbing bean in Mpungu were cultivated by almost all households, except for one household of FT4 who did not cultivate climbing bean. For all farm types, except for FT3, banana covered close to 20% of the cultivated area. For FT3 this was 13%, which was, in absolute cultivated area (ha) still more than that of FT1 and FT2. The area of climbing bean was around 20% of the cultivated area for FT1 and FT2, and only 10% for FT4. The percentage cultivated area of sweet potato also was also largest for FT1 (17%) and smallest for FT4 (2%). Despite these differences in percentage of the farm cultivated with banana, climbing bean and sweet potato, absolute areas cultivated were still lowest for FT1, followed by FT2 and FT3, and largest for FT4, which was related to the considerable differences in cultivated area per farm type in Mpungu.

The total area of tea in Mpungu differed per farm type, where FT2 cultivated on average 0.14 ha, FT3 0.42 ha and FT4 1.81 ha, which was around 1/3 of the cultivated area for these farm types. Since FT1 did not cultivate tea, the percentages of the cultivated area with sweet potato, sorghum and cassava were higher for FT1 than for other farm types.

Table 11. The distribution of cultivated crops per farm type in Chema and Mpungu expressed in, number of households cultivating this crop per farm type (# HH), the average percentage of the farm dedicated to this crop (% of total area) and the average area (ha) per farm dedicated to this crop.

Farm type	1			2			3			4			5		
	# HH	% of total area	Area (ha)	# HH	% of total area	Area (ha)	# HH	% of total area	Area (ha)	# HH	% of total area	Area (ha)	# HH	% of total area	Area (ha)
Chema															
# HH per FT	4			4			4						4		
Bush bean	4	33	0.14	4	33	0.34	4	33	0.75	-	-	-	4	30	0.29
Banana	3	20	0.08	4	17	0.14	4	9	0.17	-	-	-	4	17	0.10
Coffee	3	17	0.09	3	8	0.05	4	9	0.16	-	-	-	4	7	0.04
Maize	3	22	0.14	3	31	0.37	4	38	0.88	-	-	-	4	32	0.28
Climbing bean[1]	3	6	0.01	3	4	0.04	2	6	0.11	-	-	-	4	8	0.04
Pasture	-	-	-	3	8	0.07	1	1	0.01	-	-	-	1	2	0.04
Irish potato	-	-	-	-	-	-	1	4	0.14	-	-	-	1	3	0.05
Groundnut	-	-	-	-	-	-	2	0	0.01	-	-	-	-	-	-
Mpungu															
# HH per FT	4			3			5			4					
Banana	4	18	0.06	3	18	0.09	5	13	0.13	4	19	0.49	-	-	-
Climbing bean	4	21	0.05	3	20	0.10	5	14	0.14	3	10	0.13	-	-	-
Sweet potato	4	17	0.05	2	11	0.05	5	10	0.08	3	2	0.08	-	-	-
Maize	2	6	0.02	2	9	0.05	5	5	0.05	3	2	0.02	-	-	-
Sorghum	2	15	0.04	2	5	0.03	4	9	0.11	3	10	0.16	-	-	-
Tea	-	-	-	3	28	0.14	4	35	0.42	4	36	1.81	-	-	-
Cassava	2	14	0.05	2	7	0.03	4	5	0.05	2	3	0.04	-	-	-
Irish potato	2	3	0.01	1	1	0.00	2	3	0.02	1	1	0.02	-	-	-
Cocoyam	2	4	0.02	-	-	-	2	1	0.01	2	0	0.02	-	-	-
Bush bean	-	-	-	1	1	0.00	1	1	0.01	1	0	0.00	-	-	-
Coffee	-	-	-	-	-	-	1	1	0.01	2	15	2.03	-	-	-
Pumpkin	-	-	-	-	-	-	-	-	-	1	1	0.02	-	-	-

[1] For Chema, per farm type, two households were selected that cultivated climbing bean on a 'bigger area' and two who did not cultivate climbing bean or cultivated climbing bean on a 'smaller area'. If there was only one or no household cultivating climbing bean on a 'bigger area', the remaining households were selected from the remaining group. For detailed distribution of climbing bean cultivation see section 5.3.7.

Farmers' perceived importance of crops

Crops that acted as double purpose crop, for own food security and as cash crop, were seen as most important in both areas. Banana, maize and 'beans' were most often mentioned as an important crop in Chema (Table 12). 'Beans' were given a lower importance score than banana and maize, this while banana and maize showed to have a similar or even a smaller cultivated area than 'beans'. Bush bean was mainly appreciated for its early yield and its importance of own consumption early in the season, some of the yield was also sold. Banana and maize were both mostly mentioned as important because of their double purpose of own consumption and the possibility of selling. Households of FT1 only mentioned reasons as, 'for own consumption' and never 'selling' as a reason why banana, maize or 'beans' were important. For coffee in Chema, it was only mentioned twice as an important crop. Coffee however, was cultivated by almost all households as the only pure cash crop in Chema and appreciated as an important source of income to pay school fees.

Table 12. Crop importance score for the three most important crops per household in Chema and Mpungu. The score is a weighted average of the average farmers perceived importance and the number of times these crops were mentioned.

Chema		Mpungu	
Maize	0.70	Climbing bean	0.61
Banana	0.64	Banana	0.59
Bush bean	0.40	Sweet potato	0.35
Coffee	0.17	Millet	0.15
Beans[1]	0.09	Sorghum	0.13
Groundnut	0.02	Tea	0.09
		Coffee	0.07
		Irish potato	0.02
		Cassava	0.02

[1] Bush bean and climbing bean were often mentioned as one. In this question it was not clear whether bush bean or climbing bean was mentioned and therefore the average for 'beans' is given.

In Mpungu, climbing bean, banana and sweet potato were most often mentioned and had on average the highest importance score. Where banana and climbing bean were both used to sell and for home consumption (by all farm types), sweet potato was mainly used as own food crop only. Banana was also appreciated as it was yielding throughout the year. Although it is a cash crop and covering an important part of the cultivated area, tea was mentioned only three times.

Typical crop rotations and their importance

Bush bean after bush bean, cultivated in the banana/coffee plantation, together with intercropping maize/bush bean after maize/bush bean (cereal/legume-cereal/legume) were the most common rotations in Chema (Annex IV). Apart from maize-maize (cereal-cereal), most rotations included legumes. Legumes were almost always intercropped. Bush bean was sometimes cultivated as a sole crop in the second season (B), after maize/bush bean (season A).

Cereal-cereal and fallow-cereal were the two most common rotations in Mpungu. Cereal-cereal was most often sorghum after sorghum, fallow-cereal was always millet after fallow. Millet was commonly the first crop cultivated after the fallow period of a field in Mpungu. Fallows were only reported in Mpungu. Legumes seemed to occur less in crop rotations in Mpungu than in Chema, which was mostly because of the importance of bush bean cultivation in Chema.

Seed source and varieties used

All farm types in Chema bought seeds for more than half of their cultivated fields, especially FT1 and FT2 bought seeds for over 90% of their cultivated fields (Table 13). Households of FT3 and FT5 used their own seeds for nearly half of their cultivated fields. Hybrid maize seeds (cv. H614 and cv. H513) were used in nearly all maize fields in Chema and obtained from local seed dealers or imported from Kenya by farmers themselves. Certified bush bean seeds were also available in nearby Kapchorwa, but none of the interviewed households used these.

In Mpungu own seeds seemed to be most important, on average for all farm types, more than half of the cultivated fields were planted with own seeds. Apart from buying seeds, also a small portion of the cultivated fields was sown with seeds that were received as a gift. Households of FT4 in particular, used their own seeds (77%), whereas other farm types planted around 40% of their fields with seed they bought. Hybrid maize varieties were not used, nor available in Mpungu. Cultivated maize, sweet potato, sorghum, cassava and yam were all reported as local names and said to be local varieties. Details on climbing bean varieties are reported in Section 0.

Table 13. Seeds source of fields cultivated; bought, from own saved seed or received as gift, for the fields this was recorded in Chema and Mpungu.

	Total # fields assessed	Bought (%)	Own (%)	Gift (%)
Chema				
FT1	17	94	6	0
FT2	20	95	5	0
FT3	12	50	50	0
FT4	-	-	-	-
FT5	18	56	44	0
Total	67	76	24	0
Mpungu				
FT1	11	36	45	18
FT2	11	36	55	9
FT3	23	43	39	17
FT4	13	15	77	8
FT5	-	-	-	-
Total	58	34	52	14

Fertilizer use

Inorganic fertilizers were widely available in Chema and sold per kilo in small shops in the village and in nearby Kapchorwa. Fertilizers (NPK-blend) in Mpungu were only obtained through the tea company through a loan scheme and repaid by delivering tea to the company. A project to increase Irish potato cultivation (IFDC through Africa 2000 Network), trained two shop keepers in nearby villages to sell fertilizers (DAP and NPK, also per kg)

The number of households using inorganic fertilizers and the amounts used per household in both areas differed per farm type (Table 14). Households of FT3 and FT2 in Chema used most inorganic fertilizers. In Mpungu, only households of FT3 and FT4 applied inorganic fertilizers, households of FT4 applied most. Inorganic fertilizers were only applied to fields containing maize in Chema (mostly maize/bush bean in the lowlands), except for one household of FT4 who applied urea to Irish potato. Urea and secondly DAP were used most, some farmers used CAN. P fertilizers were only applied in the highlands in the form of DAP to one coffee/maize field (FT5) and one maize/climbing bean field (FT1). In total 19 out of 88 fields assessed in Chema received N as inorganic fertilizer (average application rate was 72 kg ha^{-1}, SE 14.6) and 8 fields received P (average 30 kg ha^{-1}, SE 6.6). Considerable variation in application rates was found for both N and P. In Mpungu, inorganic fertilizers were only applied as NPK (15-15-15) and only to 10 tea fields out of the 144 assessed fields.

Manure or organic fertilizers were collected by 15 out of 16 households in Chema and only applied to the banana-coffee gardens. One household of FT5 bought manure from cattle owners in the lowlands and applied it to a maize-bush bean field in the lowlands. In Mpungu organic fertilizers like manure were used on a wider variety of crops and applied to most fields by FT3 and to least fields by FT1 (only to the banana garden). Although 14 out of the 15 households who collected manure applied it to their banana garden, it was also applied to climbing bean (7/15), sorghum (2/15), coffee (2/15) and Irish potato (1/15).

Table 14. Inorganic and organic fertilizer use per farm type in Chema and Mpungu in 2014A.

Farm type	#HH /FT	Inorganic fertilizer use							Organic fert. use	
			N		P		K			
		# fields applied/HH	# HH	Rate[1] (kg ha^{-1})	# HH	Rate[1] (kg ha^{-1})	# HH	Rate[1] (kg ha^{-1})	# HH	# fields applied/HH
Chema										
1	4	1.0	1	61	1	67	-	-	3	1.0
2	4	1.3	3	91	-	-	-	-	4	1.8
3	4	1.8	4	107	1	40	-	-	4	1.5
4	-	-	-	-	-	-	-	-	-	-
5	4	1.8	4	27	4	22	-	-	4	1.0
Mpungu										
1	4	-	-	-	-	-	-	-	3	1.0
2	3	-	-	-	-	-	-	-	3	1.7
3	5	1.0	2	43	2	20	2	23	5	3.0
4	4	2.7	3	101	3	47	3	53	4	2.0
5	-	-	-	-	-	-	-	-	-	-

[1]Average application rate for fields receiving this type of inorganic fertilizers.

5.3.5 Fields: Comparing soil fertility

Soils were poorer in Mpungu than in Chema. Although average OC and total N fractions were higher in Mpungu, averages for pH, available P and available cations Ca, Mg and K were considerably lower in Mpungu (Fig. 8, Fig. 9, Table 15, Annex V, Annex VI). There seemed to be slight negative correlations between OC and the clay fractions which were unexpected (Chema P=0.064, Mpungu P=0.296), as were the high OC percentages in both places (Fig. 8). Organic matter in Mpungu was however of poorer quality as the average C:N ratio was higher in Mpungu (16.0) than in Chema (12.0) (Fig. 8B). The negative relation between available cations (Ca+Mg+K) and clay fractions in Chema (P<0.001) might be related to the high clay fractions (average 50%) (Annex V). Available cations were as expected positively related to pH (Chema P<0.001, Mpungu P<0.001) and total N was positively related to OC content in Chema (P=<0.001). Available P showed a number of higher values (Fig. 9C, Annex V), which could be the result of repeated manure and household waste inputs as most of these higher values were found in fields closer to the homestead. The median of available P was 9.21 mg/kg for Chema and 4.45 mg/kg for Mpungu. For Mpungu there seemed a range of fields with higher available K and a range with lower available K (Fig. 8C). This distinction was related to fields being closer to the homestead which had highest amounts of available K, possibly due to repeated inputs of ash, household waste and/or manure in these fields. Median available K was 2.7 $mmol_{(+)}$/kg in Mpungu (Fig. 9D).

A relation between walking distance and fertility indicators seemed also to be present for P, Ca and Mg in Mpungu and only for available P and K in Chema (not shown). No relation between available Ca and Mg and walking distance in Chema can be due to the different soil types in Chema and Mpungu. No relations were found between soil fertility indicators and elevation, farmers' estimated soil fertility class or farm type in both areas (not shown). Only fields of FT4 in Mpungu on average seemed to have a slightly higher pH and available P, Ca, Mg, and K than other farm types, which can be related to the larger number of livestock owned by FT4. Farmers' estimated soil fertility class (poor, medium, good) showed only slight relations to more favourable soil fertility indicators for P and Ca in Chema and P and K in Mpungu (Annex VII).

Soil fertility and typical crops

When considering the differences in soil fertility indicators between typical crops in Chema and Mpungu, overall, banana/coffee fields in Chema and banana fields in Mpungu seemed most fertile for both locations (Table 15). In Chema, farmers' estimated soil class was highest for the maize fields in the lowlands and lowest for 'bigger area' climbing bean fields. Only 'bigger area' climbing bean fields were distinguished for soil sample analysis in Chema as these contained higher percentages of climbing bean, 'smaller area' climbing bean fields were mostly banana/coffee fields intercropped with a low percentage climbing bean. This higher farmers' estimated soil fertility class for lowland maize fields might correspond to their higher available P, Ca and Mg than the other fields, which can be caused by the different position of these fields within the landscape than the other, highland, fields. The lower soil fertility score for 'bigger' climbing bean fields could correspond to their lower available P and K and the higher clay fractions. Medians for available P were as well shown in Table 15 as the results for available P were highly skewed due to some relatively high available P values. Banana/coffee had the best farmers' soil fertility score for highland fields, which could correspond to the higher (median) available P and K for these fields being closest to the homestead.

Average farmers' estimated soil class in Mpungu was lowest for sorghum, while soil fertility indicators showed no differences from the average (Table 15). Average farmers' estimated soil fertility class for other crops showed no differences from the average. Banana fields, which were often closer to the homestead, contained on average more available P, Ca, Mg and K than fields with other crops and had the highest pH. Soil fertility indicators for climbing bean fields did not differ from the average or for example from other annual crops like sorghum. Tea fields had a low pH and except for N and OC, also other indicators were smallest for tea fields.

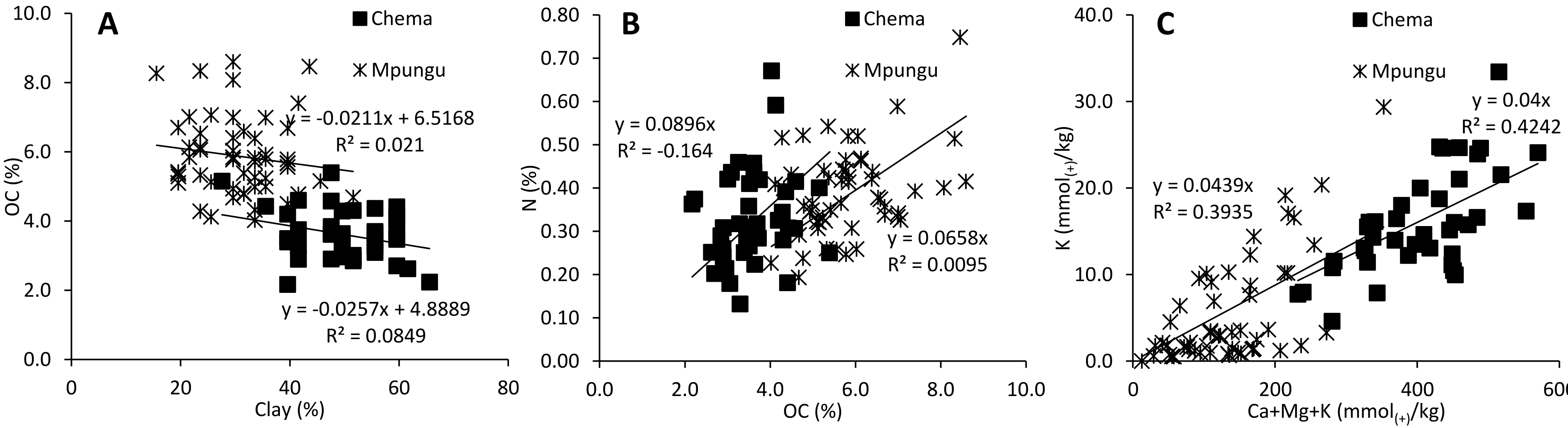


Fig. 8 Relationship between the OC fraction and the clay fraction (A), total N and the OC fraction (B), and available K and Ca+Mg+K (C), (D) for fields sampled in Chema (*n* = 41) and Mpungu (*n* = 54). Relations for other soil fertility parameters can be found in Annex V.

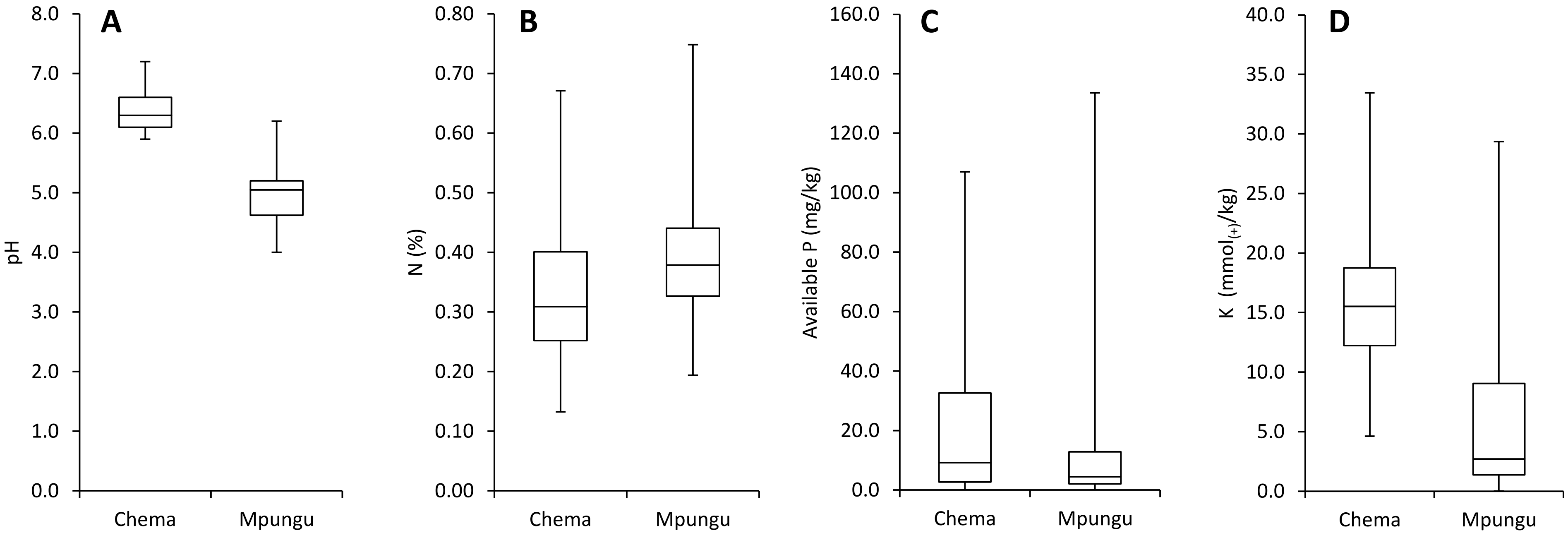


Fig. 9. Box and whisker plots (25th, 50th and 75th percentiles) illustrating the variability in pH (A), N (B), available P (C), and K (D) for soil samples taken in Chema (*n* = 41) and Mpungu (*n* = 54). Box and whisker plots for other soil fertility parameters can be found in VI.

Table 15. Averages for soil fertility indicators for all fields and per typical crop for Chema and Mpungu. SE is shown between parenthesis. Medians for P were also given as the averages were highly skewed due to some high values.

Typical crop	n[1]	Soil class[2]	Distance (minutes)	pH	OC (%)	N (%)	Available P (mg/kg)	(Median)	Ca (mmol/kg)	Mg (mmol/kg)	K (mmol/kg)	Ca+Mg+K (mmol/kg)	Clay (%)
Chema													
All fields	39	2.3	27	6.4 (0.05)	3.6 (0.12)	0.33 (0.02)	20.7 (4.0)	9.2	254 (9.9)	138 (2.9)	16 (0.9)	409 (1.1)	50 (1.3)
Banana/coffee	16	2.3	5	6.5 (0.08)	3.8 (0.17)	0.36 (0.02)	22.6 (5.3)	12.9	262 (12.2)	135 (3.3)	20 (1.3)	417 (15.8)	50 (1.8)
MaizeLL[3]	11	2.6	81	6.5 (0.09)	3.1 (0.18)	0.26 (0.02)	25.7 (7.4)	23.3	278 (18.2)	157 (2.8)	14 (1.2)	450 (20.2)	50 (2.4)
Climbing bean[5]	6	1.8	10	6.3 (0.11)	3.9 (0.18)	0.34 (0.03)	7.5 (4.7)	2.5	217 (28.5)	120 (8.2)	11 (1.3)	348 (36.2)	49 (3.6)
MaizeHL[4]	4	2.0	16	6.1 (0.10)	3.8 (0.63)	0.35 (0.11)	28.5 (26.2)	3.3	218 (47.1)	132 (7.5)	13 (3.5)	363 (53)	50 (8.0)
Irish potato	2	2.0	15	6.3 (0.20)	3.9 (0.42)	0.32 (0.10)	3.1 (2.0)	3.1	244 (11.7)	128 (0.2)	16 (2.3)	388 (9.7)	53 (3.0)
Mpungu													
All fields	54	2.3	22	5.0 (0.06)	5.9 (0.15)	0.38 (0.01)	16.5 (3.8)	4.5	81 (5.4)	51 (4.1)	6 (0.9)	137 (0.8)	31 (1.1)
Climbing bean	18	2.4	29	5.0 (0.12)	5.6 (0.27)	0.37 (0.03)	19.2 (8.4)	4.1	84 (10.4)	51 (7.8)	6 (1.7)	140 (19.0)	29 (1.8)
Banana	16	2.3	3	5.2 (0.09)	5.9 (0.30)	0.40 (0.02)	23.6 (7.1)	10.2	96 (9.2)	70 (7.1)	9 (1.6)	176 (15.9)	33 (1.8)
Tea	8	2.4	35	4.4 (0.14)	6.7 (0.44)	0.46 (0.05)	5.3 (1.8)	4.3	47 (13.1)	24 (6.5)	1 (0.2)	73 (19.4)	32 (2.4)
Sorghum	8	2.0	27	5.1 (0.14)	5.7 (0.15)	0.36 (0.03)	13.0 (8.4)	4.5	81 (9.6)	46 (6.5)	4 (1.1)	131 (16.3)	29 (2.9)
Maize	4	2.5	33	5.0 (0.09)	5.4 (0.55)	0.27 (0.03)	3.2 (1.6)	2.8	69 (8.5)	37 (3.1)	2 (0.6)	108 (11.0)	34 (6.2)

[1] *n* is the number of fields sampled. [2] Soil class is the farmers' estimated soil class. (1=poor, 2=moderate, 3= good) [3] LL = lowlands. [4] HL = highlands. [5] These were the fields selected as 'bigger' climbing bean fields in Chema. Other fields, containing a 'smaller area' of climbing bean were all banana/coffee fields.

5.3.6 Fields: Yields as related to management and environment

Intercropping

Most crops were intercropped. For climbing bean in Chema there was a significant relation between percentage intercropping of climbing bean in a field and climbing bean grain yield (R^2 = 0.58, P < 0.001, Fig. 4A). Since also for other crops it seemed that a correction for intercropping would result in yields lower than or corresponding to monoculture yields (Annex VIII), these yields were corrected for percentage intercropping, resulting in calculated sole crop yields which were used for further analysis. Bush bean yields (both high and lowland cultivation) in Chema were not transformed to sole crop yields as this would result in unrealistically high yields for fields with low percentages of bush bean (Annex VIII). That no relation was found might be due to poor yield estimations and/or the difficulty to assess percentage intercropping. Results for bush bean yields were therefore interpreted with care.

Outliers for sorghum (3050 kg ha^{-1} for 40% sorghum) and maize (1600 kg ha^{-1} for 60% maize) yields in Mpungu were omitted for further analysis (Annex VIII). Maize 2013A yields in Chema were not corrected for intercropping as percentage intercropping was not known.

Comparing yields

Climbing bean was the only crop grown in both Chema and Mpungu in 2014A and therefore the only crop yield that could be compared between the two areas (Table 16). Average climbing bean yields were nearly half those in Mpungu (811 kg ha^{-1}) than in Chema (1457 kg ha^{-1}). Comparing these two yields however, might be ambiguous since season A in Chema is the longer cropping season whereas in Mpungu this is the shorter cropping season. Rains also stopped early in 2014A according to farmers in Mpungu. Climbing bean yields for 'smaller area' fields were half those of 'bigger area' fields in Chema. When looking at maize yields for Chema in 2013A and Mpungu in 2014A, maize yields seemed also lower in Mpungu than in Chema. Smaller yields in Mpungu can be related to the generally poorer soil fertility in Mpungu.

Average climbing bean yields not corrected for intercropping (983 kg ha^1) were double those of (not corrected) bush bean yields. With low percentage climbing bean or bush bean in a field (<50% intercropping) however, uncorrected grain yields in the high lands seemed comparable for bush (average 438 kg ha^{-1}) and climbing bean (average 472 kg ha^{-1}, Annex VIII). Climbing bean showed

Table 16. Average yields of all annual crops as assessed in Chema and Mpungu for the cropping season of 2014A. SE is shown between parentheses. Yield estimates were based on measured field size (except for the millet 2013B in Mpungu) and the quantity of harvested product, which was assessed differently for some crops, depending on the method of assessment.

	Chema			Mpungu			Method of yield
	n	Yield (kg ha^{-1})		*n*	Yield (kg ha^{-1})		assessment
Corrected for intercropping							
Climbing bean (all)	15	1457	(235)	26	811	(142)	Farmer measured
Climbing bean 'smaller'	9	1019	(263)				
Climbing bean 'bigger'	6	2113	(275)				
Sorghum				19	607	(148)	Farmer estimated
Maize				18	890	(142)	Farmer estimated
Not corrected for intercropping							
Bush bean HL	25	457	(74)				Farmer estimated
Bush bean LL	16	350	(38)				Farmer estimated
Maize LL 2013A	14	1275	(169)				Farmer estimated
Maize HL 2013A	5	2821	(1451)				Farmer estimated

LL=lowlands, HL=Highlands

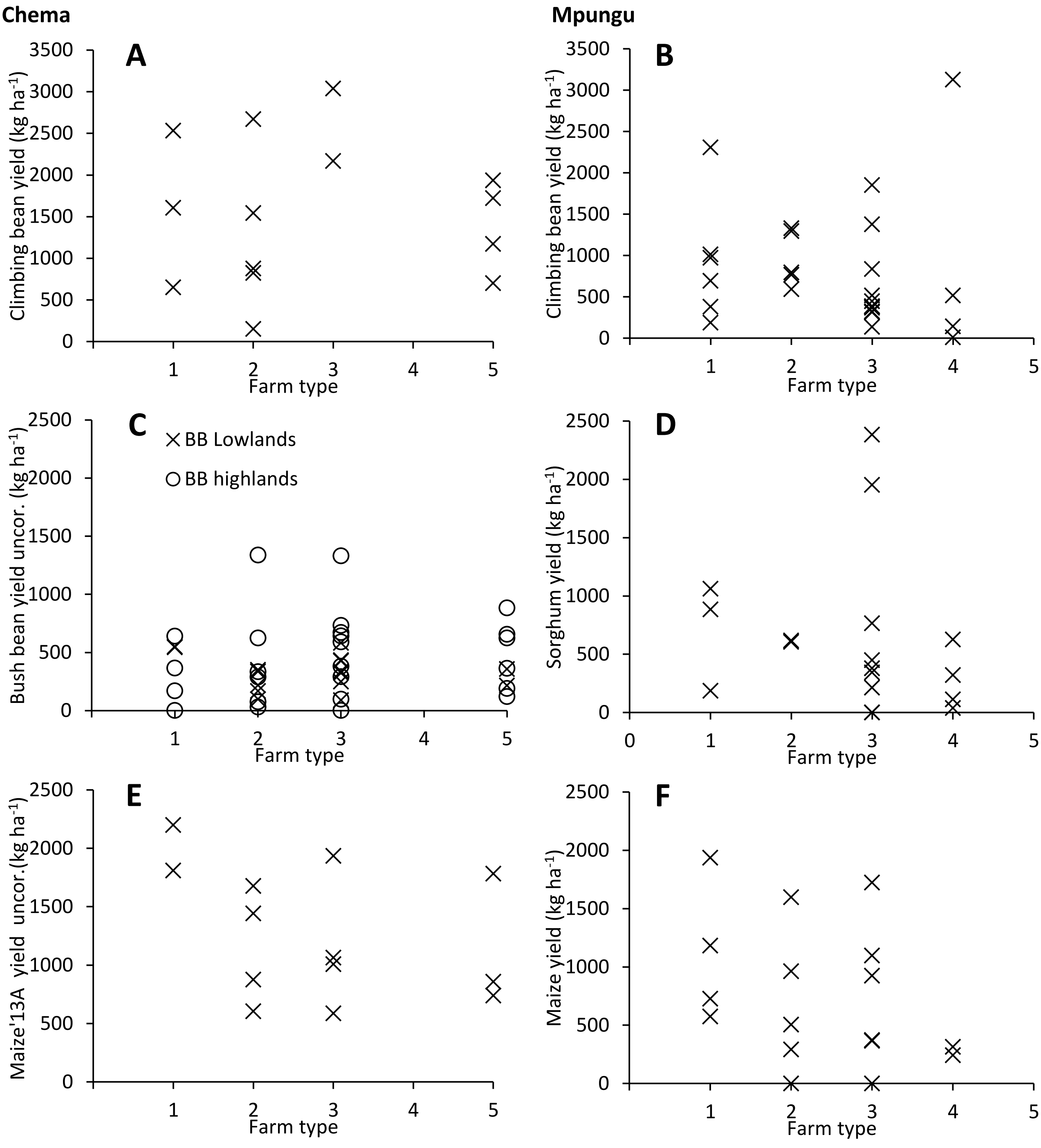


Fig. 11. Climbing bean (A), bush bean (C) and maize 2013A (E) grain yields per field for Chema and climbing bean (B), sorghum (D) and maize (E) grain yields per field for Mpungu as related to Farm type.

therefore no advantage over bush bean if both were intercropped with less than 50% (area), in banana/coffee fields for instance.

Bush bean yields in the lowlands (average 350 kg ha^{-1}) seemed somewhat lower than in the highlands (average 457 kg ha^{-1}), while percentage intercropping of bush bean in the lowlands was on average higher (more bush bean) than in the highlands. The lower bush bean yields in the lowlands might be caused by the hotter and dryer climate there.

Grain yields for all assessed annual crops showed no difference between different farm types in both locations which might be related to the low number of fields assessed per crop per farm type (Fig. 11). Even though a larger number of fields per farm type were assessed for bush bean in Chema

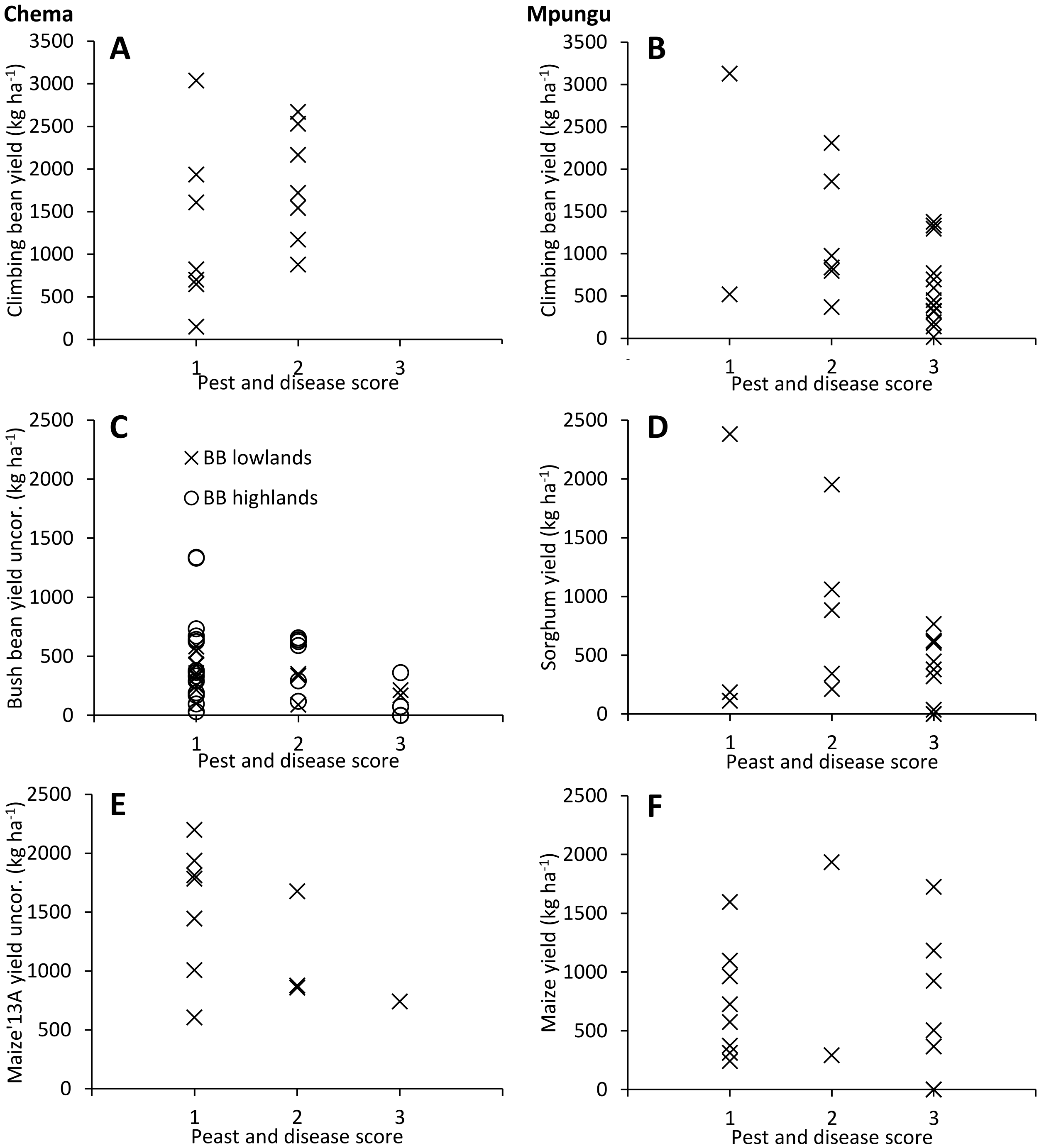


Fig. 12. Climbing bean (A), bush bean (C) and maize2013A (E) grain yields per field for Chema and climbing bean (B), sorghum (D) and maize (F) grain yields per field for Mpungu as related to pest and disease score (1=yields not affected; 3=yields seriously affected due to pest and/or diseases).

and climbing bean in Mpungu, no differences in yields per farm type were observed. For bush bean in Chema this might be because of the difficulty of assessing yields and percentage intercropping.

Low pest and disease scores were given to climbing bean in Chema (Fig. 12A). For both types of bush bean and lowland maize in Chema it seemed that larger yields were only obtained when the pest and disease score was low (Fig. 12 C and E). Lower yields however, were found for all three pest and disease scores. Climbing bean and sorghum in Mpungu were mostly given a high pest score and only few a low pest score (Fig. 12 B and D). It seems therefore that pests/diseases are perceived as an important problem for climbing bean (rats and birds) and sorghum (birds) cultivation in Mpungu.

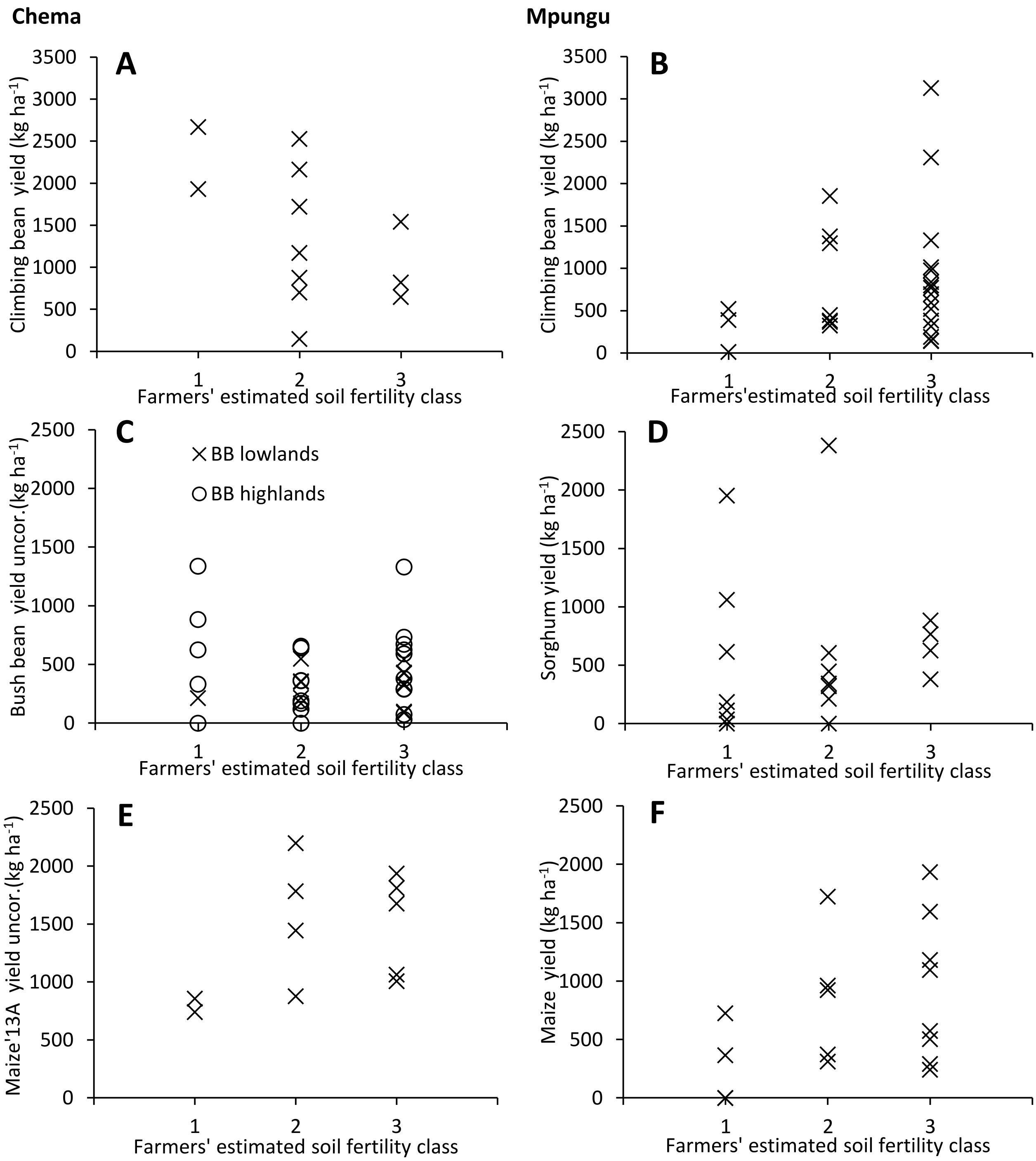


Fig. 13. Climbing bean (A), bush bean (C) and maize 2013A (E) grain yields per field for Chema and climbing bean (B), sorghum (D) and maize (F) grain yields per field for Mpungu as related to farmers' estimated soil fertility class where 1=poor, 2=medium, and 3=good.

No relation between farmers´ estimated soil fertility class and yields was observed in Chema (Fig. 13 A, C and E). In Mpungu, for all three crops assessed it seemed that higher yields were only obtained in fields with a higher farmer estimated soil fertility class. Lower yields however, were found for all three soil fertility classes (Fig. 13 B, D and F).

For both types of bush bean in Chema and climbing bean and sorghum in Mpungu it seemed that higher yields were only achieved closer to the homestead (Fig. 14). Lower yields however, were found at all distances to the homestead. Highest bush bean yields were found in the highland fields, which might be caused by the earlier mentioned more favourable climate in the highlands than in the lowlands. Climbing bean in Chema showed an opposite relation (*P*=0.050), where higher yields were

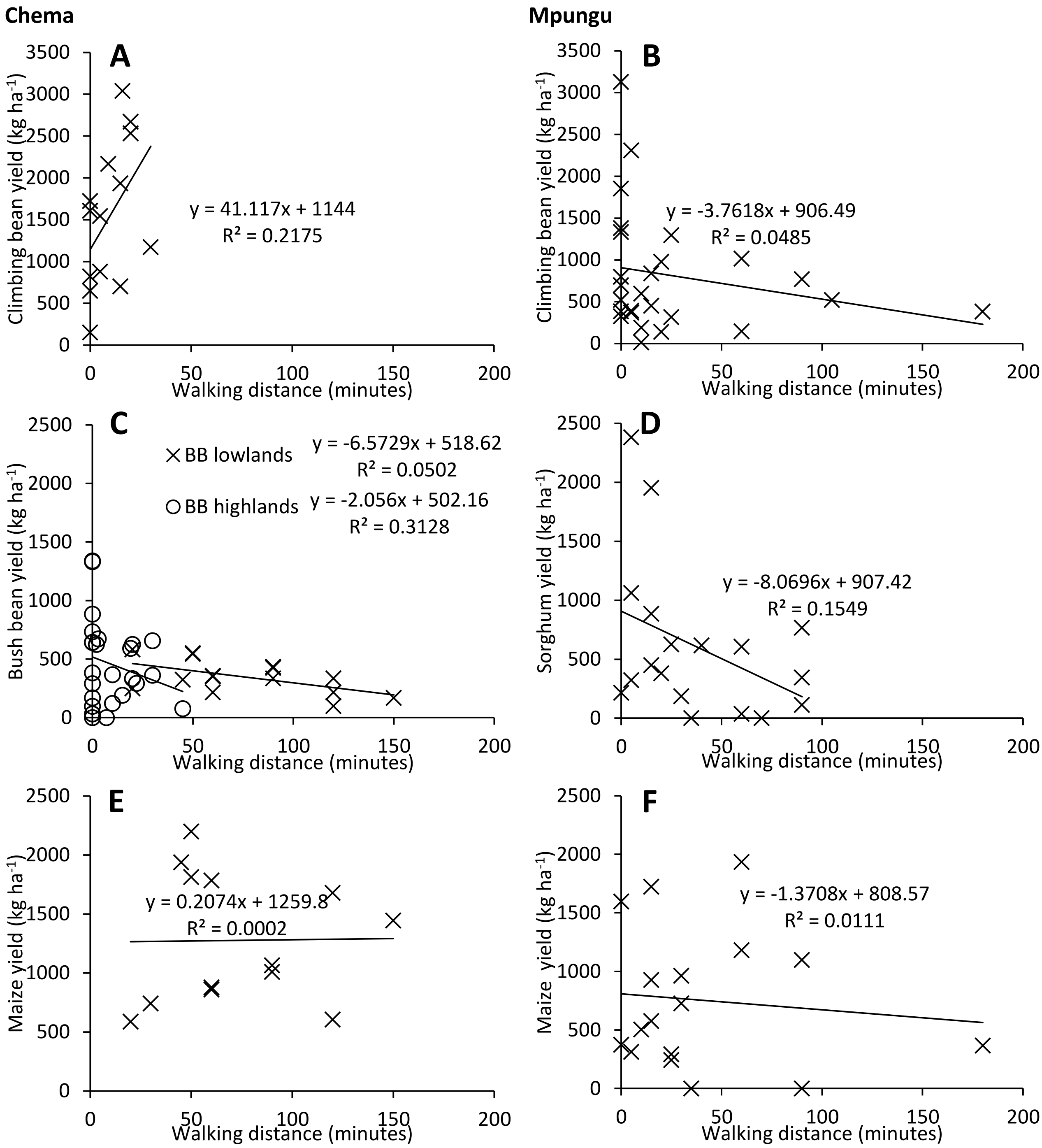


Fig. 14. Climbing bean (A), bush bean (C) and maize 2013A (E) grain yields per field for Chema and climbing bean (B), sorghum (D) and maize (F) grain yields per field for Mpungu as related to farmer estimated walking distance from the homestead to the field. Simple regression analysis was conducted to assess relations between grain yields and walking distance.

obtained further from the homestead. This unexpected relation was most probably because of 'smaller area' fields being closer to the homestead (often within the banana/coffee garden) and 'bigger area' fields being further away from the homestead. Lowland maize in Chema showed no relation between yield and walking distance.

5.3.7 Current climbing bean cultivation

'Smaller area' climbing bean cultivation (57% of the households) was more common in Chema than 'bigger area' climbing cultivation (11% of the households) according to the RFC (Annex IX). 'Bigger area' climbing bean fields were cultivated most by households focusing on agriculture for income (4 out of 8 FT3, 2 out of 8 FT2). 'Smaller area' climbing bean was cultivated equally by all farm types in Chema.

No households of FT1 in Chema could be selected that cultivated a 'bigger area' of climbing bean and therefore only for FT2, FT3 and FT5 two households per farm type were selected cultivating a 'bigger area' (Table 18). Of the households that were selected for not cultivating climbing bean or cultivating 'smaller area' climbing bean fields, only three households (four fields) of FT1 and one household FT5 (one field) were selected that cultivated a 'smaller area' climbing bean.

Of the six households cultivating a 'bigger area' climbing bean in Chema, two households of FT3 and one household of FT5 were sole cropping climbing bean, the three other households used intercropping. Of the households cultivating a 'bigger area' of climbing bean, households of FT3 were cultivating the biggest area, on average 0.218 ha. Households cultivating a 'smaller area' of climbing bean on average cultivated an area of 0.009 ha. For all households cultivating a 'bigger area' this was 0.108 ha. The percentage of the farm cultivated with climbing bean on average was 5% for the households with a 'smaller area' and 10% for the households with a 'bigger area'. Of the households cultivating a 'smaller area' of climbing bean, for FT1 and FT2 this was a bigger area than for FT5.

A larger percentage of households in Mpungu were cultivating climbing bean than was expected from the RFC. In the RFC 66% of the households said to cultivate climbing bean (Annex IX). During the DFC it was found that 15 out of 16 households cultivated climbing bean (Table 18). All households cultivating climbing bean in Mpungu cultivated a 'bigger area' and intercropping was always more than 90%, which was also higher than found in the RFC (Annex IX). Total cultivated area of climbing bean differed per farm type in Mpungu and was smallest for FT1 (0.053 ha) and biggest for FT4 (0.174 ha), whereby FT2 and FT3 showed intermediate figures (0.99 and 0.138 ha respectively). The proportion of the farm cultivated with climbing bean was however bigger for FT1 and FT2 (around 20%) than for FT3 and FT4 (both 14%), this was mostly related to the bigger area of other crops like tea for FT3 and FT4 than for FT1 and FT2.

The percentage of the farm cultivated with climbing bean in Mpungu was found to be bigger than in Chema. However, when comparing average total cultivated area of climbing bean for all households with a 'bigger area' in Chema with those in Mpungu, this was similar.

Stakes and staking

In Chema, stakes were bought for most fields (Table 17). Farmers described variations in price, between for example types (bamboo USH 50/stake, eucalyptus USH 100/stake) or stake length. The average price quoted in Chema was USH 87.5 stake^{-1}, varying from USH 50-150, and USH 10-20 stake^{-1} in Mpungu. Most farmers used eucalyptus stakes in Chema, some used coffee prunings or bamboo (from the national park). In Mpungu only three farmers had bought stakes for their climbing bean field. Mostly pine and eucalypt branches were used in Mpungu and some used Napier grass which was mostly available from their own farm and grown on the bench of their terrace.

Table 17. Source of stakes in the accessed climbing bean fields in Chema and Mpungu.

	n	Bought (%)	Own (%)	Bush (%)	Bought+own (%)
Chema	16	50	19	6	25
Mpungu	27	19	48	33	0

Only single staking was observed in both sites. In Chema one farmer mentioned that she had seen tripods of the N2Africa demonstration field in Chema. Two farmers in Mpungu mentioned a method of single staking where the stakes are put in an angle, so that less flowers are damaged by birds.

Table 18. Occurrence of climbing bean, importance of intercropping and the average cultivated area of climbing bean amongst different farm types in Chema and Mpungu as found in the DFC. In Chema, where possible, two households were selected who cultivated climbing bean on a 'bigger area' (>30 m^2 and intercropping with >30% climbing bean) and two households who cultivated a 'smaller area' of climbing bean (<30 m^2 or intercropping with <30% climbing bean) or no climbing bean.

			HH cultivating a 'smaller area' of CB (CB on < 30 m^2 or intercropping < 30%)				HH cultivating a 'bigger area' of CB (CB on > 30 m^2 and intercropping > 30%)			
Farm type	# HH/FT	# HH with no CB	# HH	Average % CB in CB fields	CB area per farm[1] (ha)	% of the farm cultivated with CB[2]	# HH	Average % CB in CB fields	CB area per farm[1] (ha)	% of the farm cultivated with CB[2]
Chema										
1	4		3	27	0.011	8	0	-	-	-
2	4	1	1	5	0.013	3	2	34	0.060	6
3	4	2	0	-	-	-	2	100	0.218	13
4	-	-	-	-	-	-	-	-	-	-
5	4	0	2	53	0.004	0	2	70	0.045	12
Total	16	4	6				6			
Average				32	0.009	5		68	0.108	10
Mpungu										
1	4	0	0	-	-	-	4	93	0.053	21
2	3	0	0	-	-	-	3	97	0.099	20
3	5	0	0	-	-	-	5	91	0.138	14
4	4	1	0	-	-	-	3	94	0.174	14
5	-	-	-	-	-	-	-	-	-	-
Total	16	1	0				15			
Average				-	-	-		93	0.115	17

[1] $\text{CB area per farm} = \sum_{i=1}^{n} CB\%_{(i)} \times Area_i$

[2] % of the farm cultivated with CB = CB area per farm/total cultivated area per farm.

HH=households, FT= farm type, CB=climbing bean.

Planting and staking

'Smaller area' climbing bean fields showed a considerable variation in management. Although on average, 'smaller area' fields in Chema had a higher planting and staking density and more plants per stake than the 'bigger' fields (Table 19), this was mainly caused by two fields that had a very high plant and stake density. Stake length was similar for both types of fields in Chema. For the 'bigger area' climbing bean fields, households of FT3 were using a higher plant and staking density and a longer stake length than households of FT2 and FT5. Stakes were found to be shortest for FT5.

Average plant and stake density seemed higher in Mpungu than in Chema. Average stake length was found to be 10-15 cm smaller in Mpungu than in Chema. Average planting density was highest for FT3 in Mpungu and staking density was also somewhat higher for FT3. Other parameters showed no differences.

Table 19. Average plant and staking density and average stake length per farm type in Chema and Mpungu. A distinction was made between 'smaller area' and 'bigger area' fields in Chema, these two types of fields are shown separately. Only the averages for 'smaller area' fields were given as almost all fields belonged to households of FT1 and only one field belonged to a household of FT5. All parameters were not corrected for percentage intercropping. SE is shown between parenthesis.

	n	Plants ha^{-1}		Stakes ha^{-1}		Plants stake^{-1}		Stake length (m)	
Chema 'smaller area' climbing bean fields									
Average	5	278000	(67000)	31000	(910)	10	(1.7)	1.75	(0.169)
Chema 'bigger area' climbing bean fields									
FT1	0	-		-		-		-	
FT2	2	136000	(26000)	16000	(600)	9	(2.1)	1.78	(0.021)
FT3	2	209000	(5000)	28000	(1900)	7	(0.3)	2.07	(0.003)
FT4	-	-		-		-		-	
FT5	2	116000	(21000)	21000	(5000)	6	(0.4)	1.58	(0.004)
Average	6	153000	(20000)	22000	(2700)	7	(0.8)	1.81	(0.114)
Mpungu									
FT1	2	218000	(97000)	31000	(13500)	7	(3.4)	1.67	(0.034)
FT2	5	202000	(39000)	21000	(2400)	8	(0.6)	1.69	(0.006)
FT3	9	358000	(75000)	33000	(3300)	9	(1.4)	1.64	(0.014)
FT4	4	238000	(56000)	27000	(4500)	9	(1.1)	1.62	(0.011)
FT5	-	-		-		-		-	
Average	20	281000	(40000)	29000	(2500)	9	(0.8)	1.65	(0.028)

Median time of staking in Chema was late April, about one month after planting, for which the median was early April. No (significant) relation was observed between grain yield and planting date, staking date or time between planting and staking in Chema (Annex X). The median of planting was early March in Mpungu and for staking late March. Highest yields were observed at these median planting and staking times, but as these were also the most common moment for planting and staking, this does not need to be a causal relation. Staking at 20 days after planting resulted in highest yields in Mpungu and there was a trend of decreasing yields thereafter (P = 0.102, Annex X). Asking planting and staking date proved to be difficult, which might be the reason why no relations were observed in Chema and the reason for negative outcomes when calculating the time between planting and staking in Mpungu.

Grain yield as related to planting density, staking density, plants stake^{-1} and stake length

Results from 'bigger' and 'smaller area' climbing bean fields in Chema were combined as they showed similar patterns and relations (Fig. 15). Higher yields were observed with increasing plant densities in both Chema (P = 0.06) and Mpungu (P = 0.006), with very high planting densities, however (Chema, >300000 plants ha^{-1}; Mpungu, >400000 plants ha^{-1}) yields reduced again. Highest yields were obtained with planting densities of 200000 plants ha^{-1} and 300000 plants ha^{-1} in Chema and Mpungu respectively (Fig. 15 A and B).

In both areas there was a trend that highest grain yields were found with higher staking densities (Fig. 15 C and D). In particular in Mpungu however, low yields were also observed with higher staking densities. 30000 stakes ha^{-1} in Chema and 40000 stakes ha^{-1} seemed to be staking densities resulting in highest yields. Climbing bean grain yield showed no relation to the number of plants $stake^{-1}$ in both areas (Fig. 15 E and F).

Highest climbing bean grain yields were obtained with taller stakes in Mpungu (P = 0.048), low yields however, were also found with taller stakes. Stake length in Chema showed no relation to yield.

Climbing bean yields as related to soil fertility indicators

Climbing bean grain yields showed some relation to OC, total N, available-P, and the clay fractions (Fig. 16), while no relations were found with pH, nor with available Ca, Mg, and K (not shown). There seemed a negative trend for climbing bean grain yield and clay in Chema (R^2 = 0.30, P =0.062, Fig. 16A). OC seemed to be a confounding factor for this relations as there was a positive trend between climbing bean yield and OC (R^2 = 0.33, P = 0.066, Fig. 16C) and negative relation between OC and the clay fractions (R^2 = 0.50, P = 0.040, not shown) in Chema. There was a slight positive trend for climbing bean grain yields and available P (Fig. 16B). The low levels of available P might be related to the acidity of the soils in Mpungu. Available P in Mpungu seemed to have two outliers that were not related to high P inputs (fields being closer to the homestead) and were therefore not taken into account. Total N seemed to be related to climbing bean grain yields in Mpungu, where highest yields were only found with total N of around 0.4% (Fig. 16D). Low yields however were also found with this and higher fractions of total N. These three highest yields in Mpungu also had a more favourable C:N of 11.4, whereas the average C:N of the fields with lower yields was 15.9 (Fig. 16A).

Manure application did not result in significantly higher climbing bean grain yields in Chema and Mpungu (Fig. 17). Average yields in Mpungu however, were 700 kg ha^{-1} for fields receiving no manure and 1100 kg ha^{-1} for fields receiving manure, this was however not significant due to the considerable variation in yields.

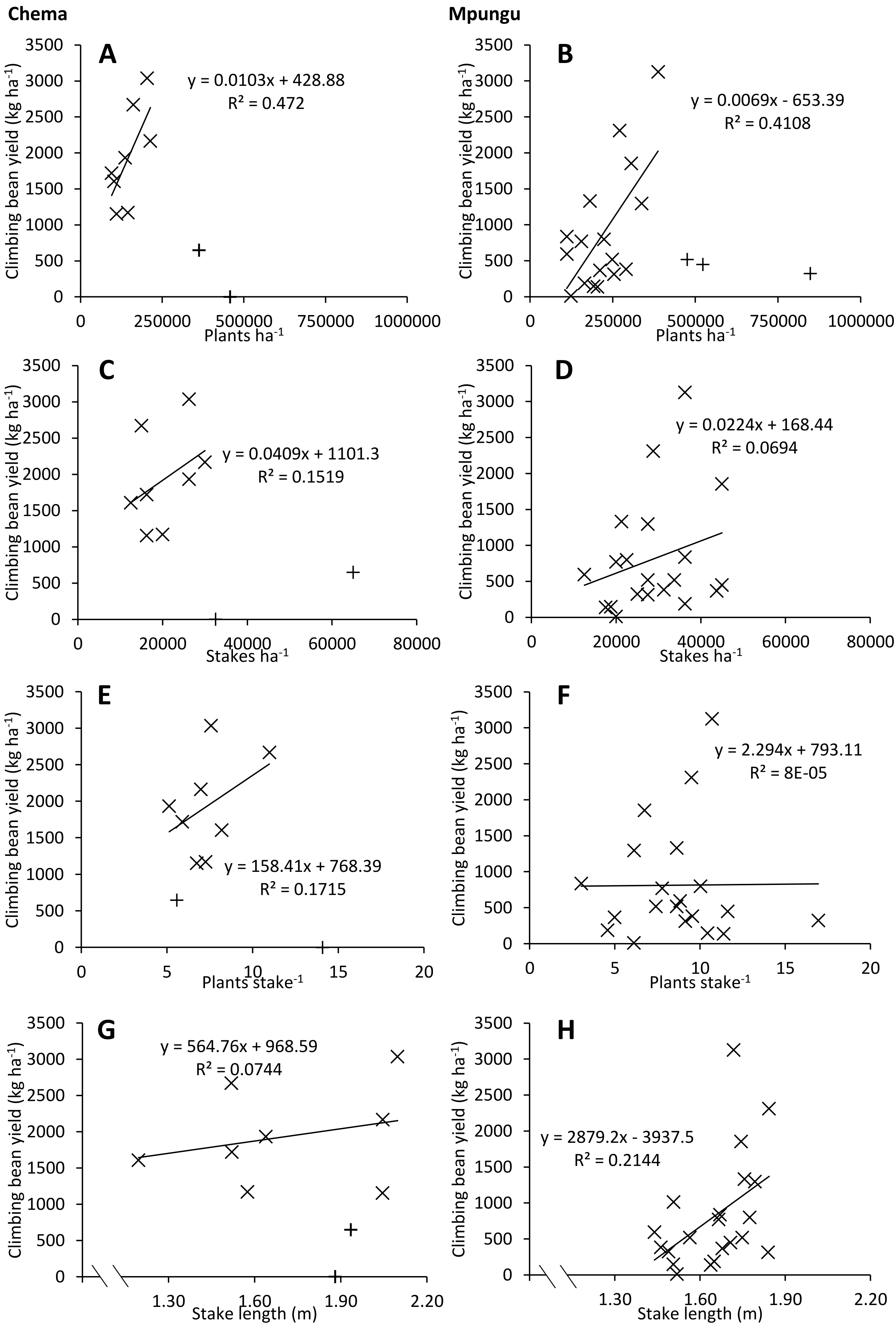
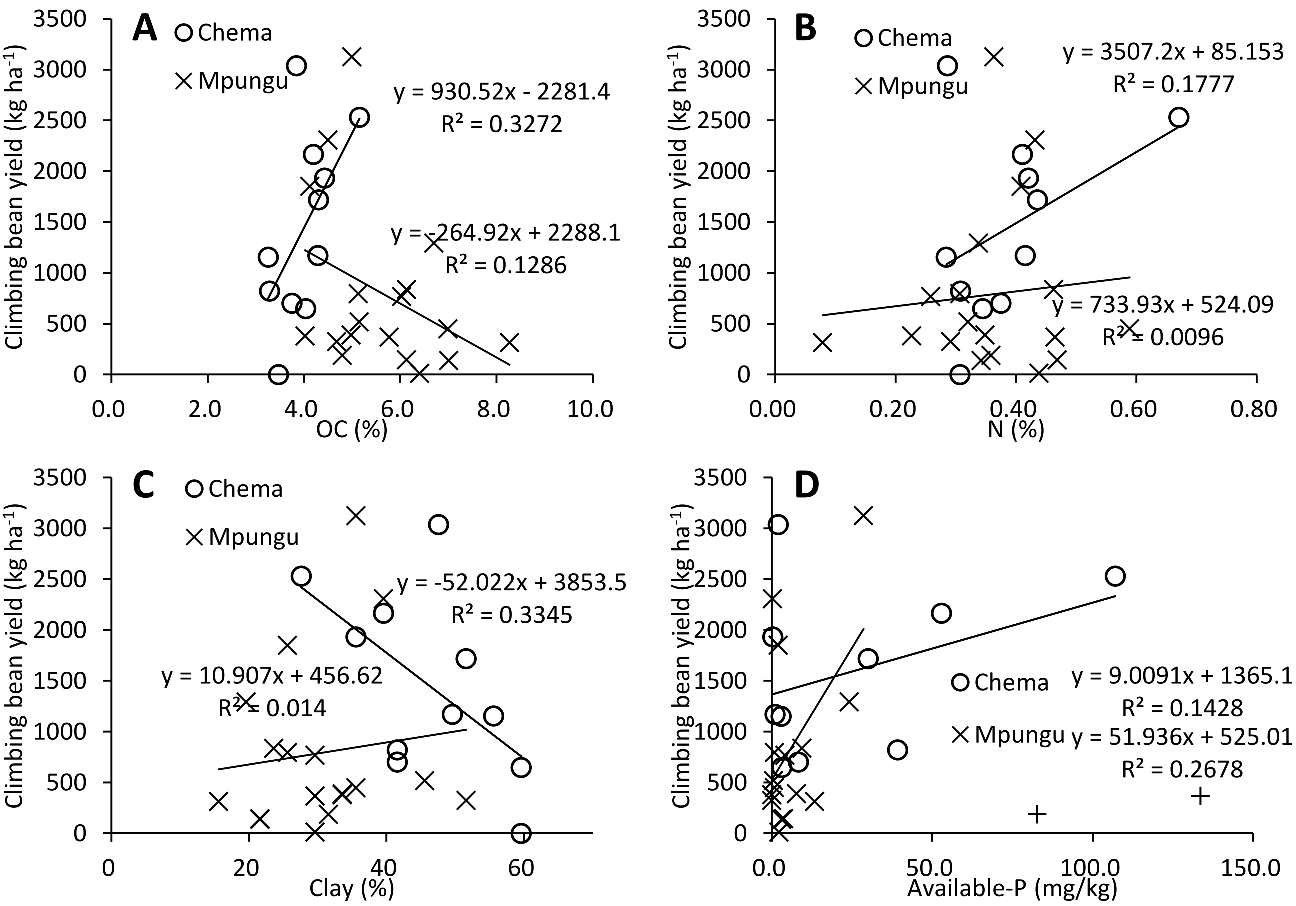


Fig. 15. Climbing bean grain yields in Chema (A, C, E, G) and Mpungu (B, D, F, H) as related to plant density (A, B), stake density (C, D), plants stake^{-1} (E, F) and stake length (G, H). Outliers (+) for plant density in Chema and Mpungu and stake density in Chema were excluded for analysis.



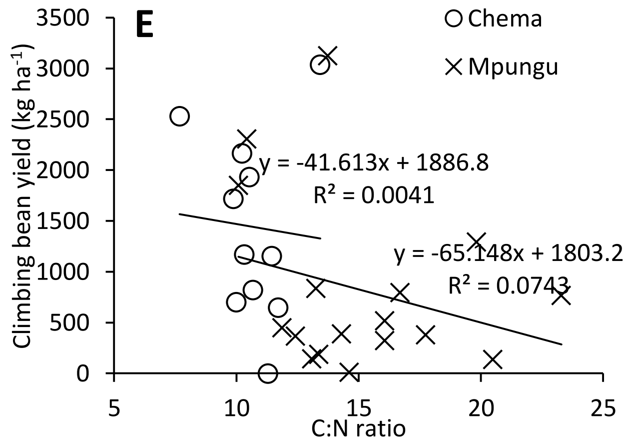


Fig. 16. Climbing bean grain yields as related to soil fertility parameters; OC (A), total N (B), clay fraction (C), plant available-P (D), and the C:N ration (E) as found in Chema (n = 12) and Mpungu (n = 18). Simple regression analysis was conducted to assess relations between grain yields and walking distance.

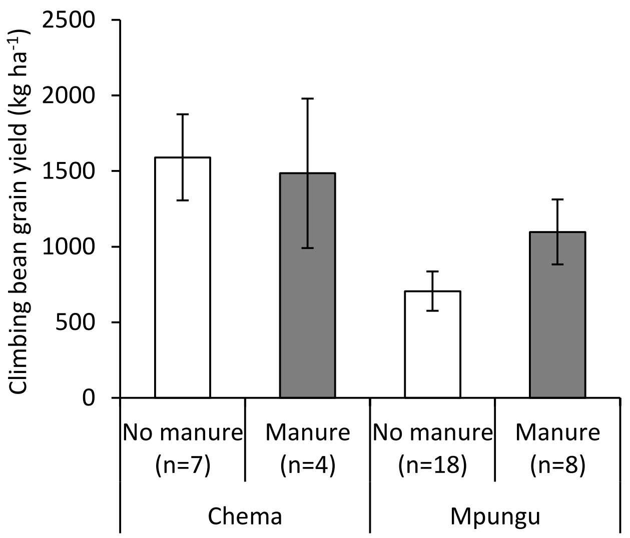


Fig. 17. Climbing bean grain yields as related to manure application in Chema and Mpungu. Error bars represent the standard error.

5.3.8 Farmers' reported opportunities and constraints

History of climbing bean cultivation
Climbing bean cultivation in Chema started about ten years ago when some farmers introduced it from Bulambuli, which is about half way between Mbale and Chema. Resource persons explained that climbing bean was first cultivated in villages closer to Bulambuli by Bagisu people, in higher altitudes than Chema-middle. It was now recognised as a relatively fast maturing crop which can be cultivated in both seasons (unlike maize for example). Apart from home consumption, its high cash value was recognized and both fresh pods and dry grains were sold to Mbale and Kampala. Local schools were also known for buying dry beans or accepting them as tuition fees.

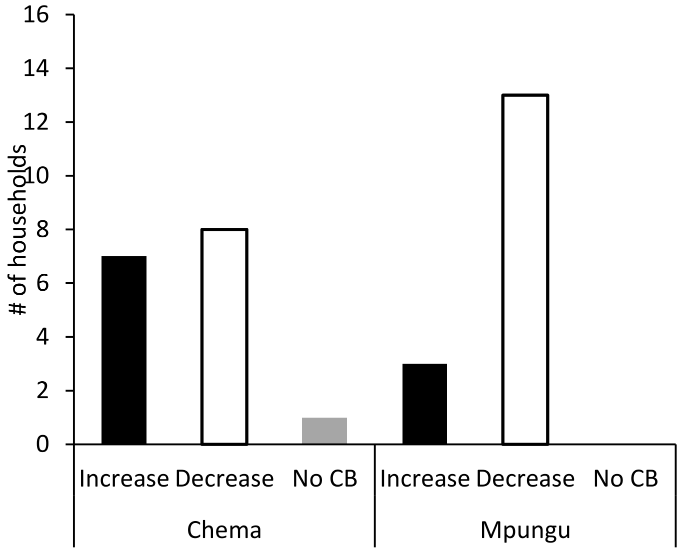


Fig. 18 Number of households in Chema and Mpungu that had increased their cultivated area of climbing bean, decreased their area of climbing bean, or no climbing bean at all (no CB) in the past three years.

Climbing bean was cultivated as long as people could remember in Mpugnu (or 'it was there when I was born'). Bush bean used to be more common in Mpungu but was currently only grown by a few households.

In Chema, only one household in the DFC had never grown climbing bean. The total area of climbing bean cultivation seemed to be stable in Chema: a similar number of households said to have increased the area of climbing bean as the number that said to have increased it (Fig. 18). In Mpungu 13 out of the 16 interviewed households said that they decreased the cultivated area of climbing bean. The most important reason to decrease the area of climbing bean was rats attacking the crop. Other reasons were bird attacks, reducing soil fertility and that intercropping was no longer allowed in banana plantations.

High yields and good prices were most often mentioned (3 and 2 times respectively, out of 16 households) as a reason to increase the cultivated area of climbing bean in Chema, whereas home consumption was most important in Mpungu (2 out of the 16 interviewed households. In both areas the importance of climbing bean as nutritious food for the children was often mentioned by farmers.

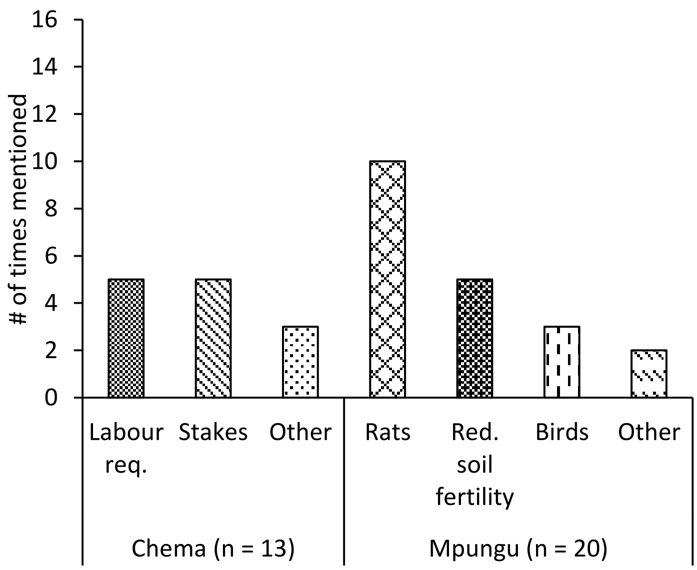


Fig. 19. Reasons mentioned in Chema and Mpungu why households decreased their cultivated area of climbing bean. Other were those reasons mentioned only once (In Kapchorwa; pest control, low yields and land shortage. In Kanungu; 'ageing' and dieback).

General constraints
Rats and reducing soil fertility were mentioned most often as general constraint for climbing bean cultivation in Mpungu (Fig. 19). Labour requirements (for staking) and availability of stakes were most often mentioned as a constraint in Chema.

Climbing bean required more

labour than maize, coffee and bush bean according to 60-100% of the households for which half of the households mentioned staking as the main cause. 80-100% of the households in Mpungu said that climbing bean took more labour than sorghum, tea and/or bush bean. Higher labour demand however was not seen as an important constraint according to 11/15 households as it was an important food crop to them (i.e. "it gives blood to the children").

Stakes from national parks

Due to high population densities around Chema, there was a high demand for stakes, timber and fire wood for example. Previously (bamboo) stakes were taken from Mount Elgon National Park. People were allowed access to the national park to gather firewood as part of a resource use agreement between the Uganda Wildlife Authority (UWA) and local communities. It was however common practice to cut down trees or bamboo for stakes. People doing this had attacked UWA rangers when they tried to stop them, resource persons reported. At the time of research the resource use agreement had ended and talks to establish new agreements had not been successful yet. Due to the incident with UWA rangers, no one was allowed to enter the forest anymore, resulting in an even increasing shortage of stakes for climbing bean cultivation.

Mpungu was located on the border of Bwindi Impenetrable National Park. This park was gazetted in 1991. It was not common (anymore) to gather wood or stakes in the forest, which might also be related to the seemingly lower land pressure and bigger areas of natural bush land and timber plantations.

Varieties cultivated

The most common climbing bean variety in Chema was cv. Atawa (official names NABE 10, G2333 and Umubano), one household was cultivating cv. Mazongoto (official name NABE 12C). Atawa is a variety with red grains which are smaller than Mazongoto. Mazongoto is a white variety with brown/red dots. Mazongoto was receiving a higher price because of its colour and size. All reported yields and fields observed in Mpungu were growing cv. Mubano. Cv. Mubano was introduced around 2007 by the NGO CARE as a high yielding variety and is most probably the same variety as cv. Atawa (official names NABE 10, G2333 and Umubano). Farmers reported that they appreciated cv. Mubano because of its high yields in the first years and therefore replaced their old varieties almost completely. However, currently yields were reducing and farmers regretted their shift to cv. Mubano. They also said that cv. Mubano was more susceptible to rat damage than the varieties they previously cultivated: another reason why they would like to grow new or their old varieties again. NAADS had a program introducing NABE 12C in the area which had not reached the studied community.

Pest and diseases

Aphids were most often mentioned by households as important pest and diseases for climbing bean in Chema. In Mpungu rats and birds were most often mentioned.

In Chema nine households mentioned spraying as a solution to aphids and blight. One of them also mentioned the correct insecticide and fungicide for both (which was the only household applying insecticide to

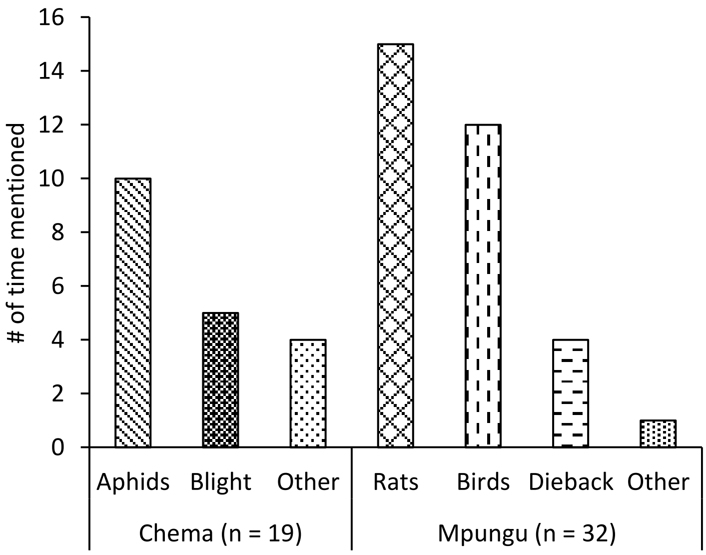


Fig. 20. Answers mentioned to the question: ´What are the most important pest and diseases in climbing bean?'. Other were those reasons mentioned only once (In Chema: 'drying of stem', dieback and 'early yellowing of leaves'. In Mpungu: baboons.)

climbing bean), others were not able to name the insecticides and fungicides needed for climbing bean. Solutions to rats and birds that were mentioned by farmers in Mpungu were almost only poison, one household mentioned traps and one guarding. Dieback in Mpungu was described as young plants dying just after emergence. Some farmers said that reducing soil fertility was causing dieback.

Input accessibility

Households were asked to list what inputs they needed for climbing bean cultivation. When this list was completed they were asked which inputs were easily available and which were difficult to obtain. The remaining inputs were listed as moderately accessible (Table 20).

Stakes and fertilizers were most often mentioned as not easily available inputs for climbing bean cultivation in Chema. Seeds were also often mentioned however, these were mostly rated as easy accessible. Labour was the fourth most mentioned input and rated as moderate or difficult to access. Stakes were rated as both easy and difficult to access (in equal numbers) in Mpungu. Seeds were most often mentioned as difficult to access in Mpungu. Labour was often named and mostly rated as moderately accessible. This was the same for tools like pangas, hoes, knives and sacks which were also mentioned as moderately available. Manure was only mentioned in Mpungu, with no clear vote for easily or difficult to access.

Table 20. Accessibility of inputs for climbing bean cultivation in Chema and Mpungu. Households were asked what inputs were needed for climbing bean cultivation, after which they were asked to rank these inputs as easy, moderately or difficult to access.

	Chema			Mpungu		
	Easy	Moderate	Difficult	Easy	Moderate	Difficult
Stakes	3	1	9	6	2	6
Seed	9	2	2	3	3	8
Fertilizer		3	8			1
Labour		3	3	2	9	2
Hoe	1	1		5	5	3
Panga	1	1		1	6	2
Manure				2	3	2
Knife					3	2
Land	2					1
Rat poison						1
Food[1]				1	3	
Sacks					5	
Other	1	1			3	
Total	17	12	22	20	42	28

[1] In Mpungu it was common to provide lunch for labourers.

Perceived effect of rotation and residue use

The perceived positive effects of climbing bean on subsequent crop yields were almost by all farmers attributed to 'leaf droppings of beans', or 'manure from beans' and similar statements (Table 21). One farmer said, 'because I apply manure to the climbing bean, sorghum in the next season does very well'.

In both places, more than half of the farmers used the bean residues as mulch in the banana field, some burned it and in Chema two farmers left it in the field. Burning was done for the ash, which is used as a food ingredient (salt).

Table 21. Perceived effects of climbing bean on a subsequent crop yields.

	Chema	Mpungu
Positive effect	9	15
No effect	3	0
Do not know	4	1

5.4 Available options to increase current climbing bean productivity

Chema

Considerable variation in grain yields was found within 'smaller area' fields and within 'bigger area' fields of climbing bean. The positive deviation from the average (difference between the highest yields and average yields) might describe how yields could improve within the current climbing bean cropping system by making use of the best technologies and practices that are already used. It assumes that if all farmers would make use of these best practices, average yield would increase towards the higher yields and the standard deviation would be reduced (Fig. 21). This assumption was based on the possible relations found in sections 5.3.6 and 5.3.7, where higher yields were related to, amongst other factors, better crop management.

Increasing planting density in Chema seemed to be an important factor as highest yields were only found above 150,000 plants ha^{-1} and below 300,000 plants ha^{-1}. Considering input availability within Chema, increasing sowing density could be relatively easy to manage by farmers and therefore be a viable option. Plant density however, also depends on emergence rates and therefore seed quality could also be considered to increase plant density. Stakes were found to be the most limiting factor for increasing climbing bean cultivation and therefore, although seemingly related to higher yields, staking density might be more difficult to increase than planting density. Based on relations found in this study, reducing the area of climbing bean, using the same number of stakes and thereby increasing staking density, would increase yields ha^{-1}. This increase however, would not be proportional to the decrease in total yield. This option can still be viable if land scarcity is prevailing and the land not cultivated with climbing bean would be cultivated with another high yielding crop. If however, this area not cultivated to climbing bean would be cultivated with bush bean, obtaining current average bush bean yields, total yield (kg) would still be lower or equal to the yield of cultivating the whole area with climbing bean with a lower stake density. Establishing such relations however, would require more detailed research and cannot be based on this study.

Higher climbing bean yields in Chema seemed to be related to higher OC contents and lower clay fractions. High clay fractions can not be reduced by management, they could however be the result of erosion of the more fertile top soil (including organic matter). Organic carbon content of the

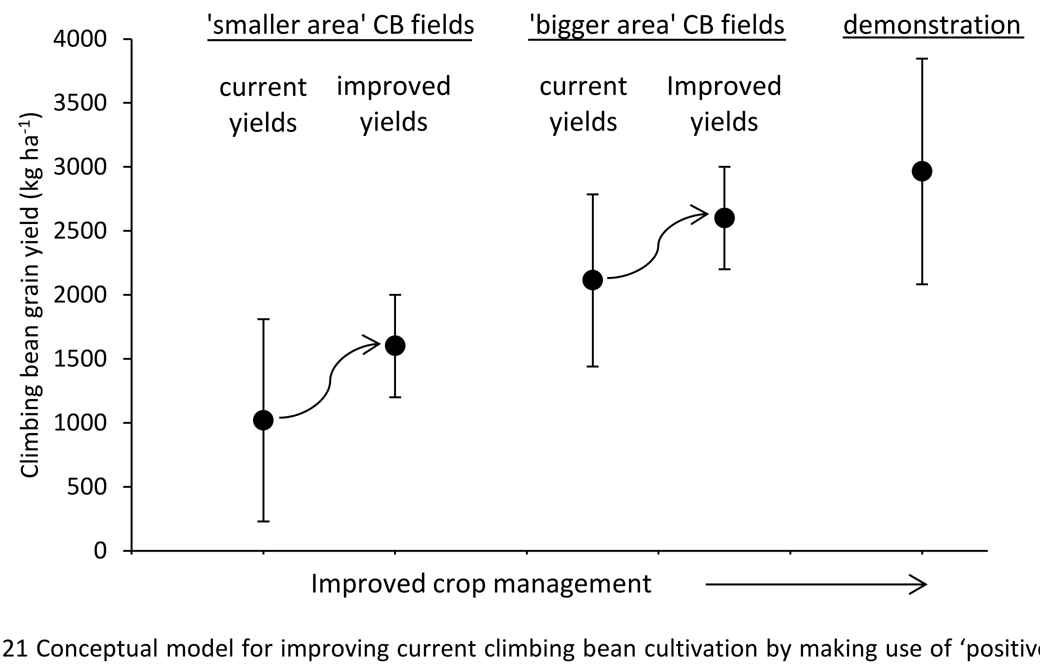


Fig. 21 Conceptual model for improving current climbing bean cultivation by making use of 'positive deviation' from the average for the current climbing bean yields within the two types of climbing bean cultivation in Chema. Error bars represent the standard deviation.

soil could be increased over time through the use of organic fertilizers like manure and maintained by applying measures to reduce erosion. Manure application however, showed no direct effects on farmers' yields and might therefore be of low interest to farmers in Chema. Manure application resulted only in higher yields in 2013A N2Africa demonstrations around Kapchorwa, in 2014A, no effects of TSP+manure were found. Also in on-farm (farmer managed) trials in 2013A and 2013B, no effects of manure application on climbing bean yields were found (all not shown).

Based on the above described relations, it was assumed that increasing plant density and staking density (improving current management with available methods) could increase average yields and to a certain extent reduce the high variation in yield currently observed (Fig. 21). Differences in soil fertility and other factors would however still result in considerable variation. 'Smaller area' fields were estimated to have a possible average yield of 1600 kg ha^{-1}, 'bigger area fields' 2600 kg ha^{-1}, which would be an increase of approximately 500 kg ha^{-1} for both types of climbing bean cultivation.

Current yields for 'bigger area' fields were already within the range of yields found in nearby demonstration fields. Averages across all demonstrated single staking treatments in Chema ranged from 2272-3619 kg ha^{-1} and an average yield over all treatments was 2965 kg ha^{-1} (Fig. 21). The possible improved yields for 'bigger area' fields would go towards the observed average yields in demonstration fields, where crop management was considerably different from farmers´ practices. Different varieties were used in the demonstration fields, planting density was lower (80000 plants ha^{-1}), staking density was higher (40000 stakes ha^{-1}, only tall stakes) and the crop was sprayed twice with pesticide and fungicide to reduce incidence of respectively aphids and blight. The additional management practices in the demonstration fields could be the reason for higher yields, even though planting densities were 1.5-2.5 lower than in farmers' fields. These demonstrated improved crop management strategies might thus to some extent substitute higher plant densities for increasing yields.

Currently, planting and staking density in 'bigger area' fields was highest for households of FT3, who were also the farm type cultivating most 'bigger area' climbing bean fields. Since these households gained most income from agriculture and for example already use inorganic fertilizers in maize fields, further investment in technologies, also for climbing bean, might be likely. Increasing staking density and, where needed, planting density can be more easy, first steps. Applying manure would also be most viable for FT3, since they often own most livestock.

'Smaller area' climbing bean fields occurred most with households of FT1, FT2 and FT5. Due to the high percentage of intercropping with other crops in these 'smaller area' climbing bean fields, high yields similar to the 'bigger area' fields might not be possible. Variation between yield however showed that yields could still be increased. Most variation for 'smaller area' fields seemed to be related to little knowledge about climbing bean cultivation technologies. Some very high staking densities (65000 ha^{-1}) or high numbers of plants per stake (14 plants $stake^{-1}$) were found for instance. Reducing this to more modest numbers would relatively easily result in higher yields, for all farm types. Increasing inputs like sowing density can still be limiting for FT1 and FT2 since they buy most of their seeds and therefore depend on their limited cash resources. The need to buy stakes might also be most limiting for these households. Alternative staking methods, requiring less stakes would therefore be an option for these 'smaller area' climbing bean farmers of FT1 and FT2.

Mpungu

In comparison with the average yield (803 kg ha^{-1}) found with farmers in Mpungu, three outstandingly high yields were found (1850, 2300 and 3100 kg ha^{-1}). These highest yields were only observed when pest score was low, soil fertility score was high, planting density was above 270,000 plants ha^{-1} (and not higher than 400,000 plants ha^{-1}), staking density was higher than 27,500 stakes ha^{-1}, stake length taller than 1.70 m, OC was 4-5% (not higher), C:N was around 10 and total N around or above 0.4%. If these conditions would be considered as prerequisites for these high yields, fulfilling these prerequisites might result in those high yields, or, at least in higher yields than the current average. This also corresponds with reasons named by farmers for decreasing their cultivated area of climbing bean, 1) pests (rodents and birds) and 2) low or reducing soil fertility . Pest control and (inorganic) fertilizer use might be the most important steps before other improved management (plant and stake density and stake length) would pay off. Although this was not available, farmers only named poison as options for pest (rodents and birds) control. Fertilizer use was currently very limited (only for tea) and fertilizers were also only available at one or two shops in nearby villages. If N2Africa or other projects could provide options for farmers to control pests and to promote fertilizer use, yields might go up to those three higher yields of around 2400 kg ha^{-1} (Fig. 22).

To put these yields into perspective, farmers' yields in Mpungu of 2014A were compared with climbing bean yields found in N2Africa demonstration fields of 2013A in Kabale region. Considerable variation in yields was found in demonstrated treatments in Kabale, with averages ranging from 863-4185 kg ha^{-1} across treatments and an average over all treatments of 2921 kg ha^{-1}. Since the number of replicates was low (n=2) and differences between averages was not as expected for different treatments, for further analysis only the average over all treatments was used. Although most yields in the demonstrations were higher than yields in Mpungu, they were in the same range as the three highest yields reported in Mpungu (Fig. 22). Whether a threefold yield increase is possible for all farm types, depends mostly on the possibility and availability of methods to control pests. Yet, these methods were not available in the area and would depend on an integrated solution where for example also projects of the government or NGOs would help to reduce the pest populations. Yield increase could be supported by other improved management. Taking into consideration the availability of inputs within Mpungu, and management currently used, increasing planting and staking density, stake length and to a certain extent manure use for climbing bean, could be more easily available options within the reach of farmers. The use of manure depends on farm type, as FT4 owned most and FT1 least livestock. If inorganic fertilizers would be used for climbing bean, application rates might also depend on farm type since investment in inputs was also highest for FT4, and lowest for FT1.

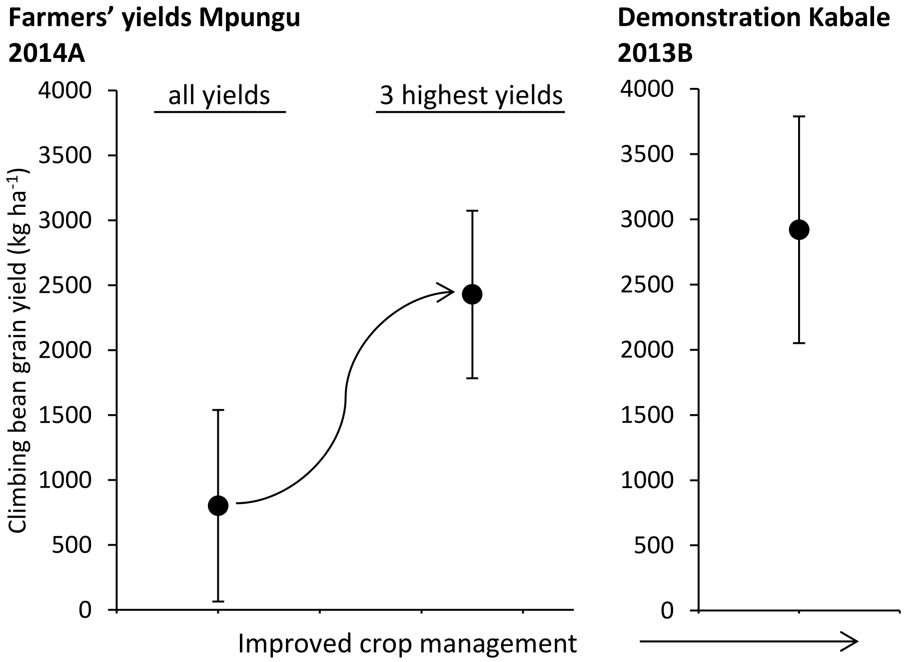


Fig. 22 Conceptual model for improving current climbing bean cultivation in Mpungu by making use of the difference in current average farmers' yields and the three highest yields achieved, which were related to better cropping conditions (soil feritlity and pest presure) and mangement. To put this into perspective, yields in demonstations fields in Kabale are shown (season 2013B). Without these three highest yields in Mpungu, the average yield would be 580 kg ha^{-1}, whereas now it was 811 kg ha^{-1}. Error bars represent the standard deviation.

Profitability of climbing bean cultivation

Input use (sowing density, stake density, etc.) was based on results from the DFC (Table 22). The improved cropping systems for climbing bean were assumed to result in improved yields as described in the previous section. Total cost for sowing and staking materials were increased according to the increased sowing density and staking density. It was assumed that labour demand would only increase for staking due to increased staking density (a proportional increase). Average labour inputs were considerably different for 'smaller' and 'bigger area' climbing bean fields in Chema and were therefore calculated separately. Stakes were used four seasons on average and cost for stakes were therefore calculated per season. Manure or inorganic fertilizers were not included as input as these were used by few farmers and demonstration results showed only limited or no yield increase.

Table 22. Current and improved input use in Chema and Mpungu.

			Chema		Mpungu
	Inputs	Unit	'Smaller area'	'Bigger area'	
Current management	Total labour input	Person-days ha^{-1}	437	949	665
	Labour staking only	Person-days ha^{-1}	47	343	176
	Planting density	Plants ha^{-1}	278000	153000	281000
	Staking density	Stakes ha^{-1}	31000	22000	29000
Improved management	Total labour input	Person-days ha^{-1}	454	938	732
	Labour staking only	Person-days ha^{-1}	46	468	243
	Planting density	Plants ha^{-1}	200000	200000	300000
	Staking density	Stakes ha^{-1}	30000	30000	40000

The high variability in input use (including very high planting and staking densities) in 'smaller' fields in Chema resulted in high cost of materials, which could be reduced by improved management (Table 23). This reduced cost for materials through improved management and the proportionally bigger increase of yields for 'smaller area' than for 'bigger area' climbing bean cultivation in Chema resulted in a bigger increase in net revenue for the 'smaller area fields'. Results of 'smaller area' fields in Chema should however be interpreted with care. Yields were corrected for percentage intercropping, while input use was not, which can result in an over-estimation of net revenue for these fields with a low percentage of climbing bean.

The low price of stakes in Mpungu resulted in relatively low costs for materials. Current low yields however, resulted in relatively low net revenue when comparing it with 'bigger area' fields in Chema. A threefold increase in net revenue could be achieved in Mpungu if the main constraints could be overcome. High labour inputs needed for climbing bean resulted in low returns to labour and low net revenue if labour was accounted for as cost. In both areas, returns to labour for climbing bean would not reach daily wages (Chema, US$ 1.77 person day^{-1}; Mpungu US$ 2.11 person-day^{-1}), also not with improved management. The proportionally bigger increase in returns to labour in Mpungu and for 'smaller area' fields in Chema when compared to 'bigger area' fields in Chema was again related to the proportionally lower increases in possible yields for 'bigger area' fields. Absolute returns to labour or net revenue for 'smaller area' and 'bigger area' climbing bean cultivation are not comparable as input use is not corrected for percentage intercropping, which particularly affects profitability of 'smaller area' climbing bean cultivation.

Table 23. Partial budget analysis of climbing bean cultivation for one cropping season using current and improved management.

		Common attributes					Returns to labour		Labour as cost	
		Yield kg ha^{-1}	Price US$ kg^{-1}	Total revenue US$ ha^{-1}	Cost of materials US$ ha^{-1}	Net revenue US$ ha^{-1}	Labour input person days	Returns to labour US$ person day^{-1}	Total labour cost US$ ha^{-1}	Net revenue US$ ha^{-1}
Current										
Chema	'Smaller'	1019	0.61	623	351	273	437	0.62	771	-499
	'Bigger'	2113	0.61	1293	234	1059	949	1.12	1676	-617
Mpungu		803	0.50	400	99	301	665	0.45	1401	-1100
Improved management										
Chema	'Smaller'	1600	0.61	979	317	662	424	1.56	748	-86
	'Bigger'	2600	0.61	1591	317	1274	1054	1.21	1862	-588
Mpungu		2400	0.50	1197	119	1078	679	1.59	1430	-353

To calculate the sowing rate (kg ha^{-1}), a conservative thousand seed weight for Atawa/Mubano was used, 400 g (Niringiye et al., 2005). Plant density depended on observed plant densities in farmers' fields.

Table 24. Partial budget analysis for two seasons (one year) of current climbing bean cultivation in comparison with other major crops in Chema and Mpungu.

Crop	Common attributes			Returns to labour		Labour as cost	
	Total revenue US$ ha^{-1} year^{-1}	Cost of materials US$ ha^{-1} year^{-1}	Net revenue US$ ha^{-1} year^{-1}	Labour input Person-days ha^{-1} year^{-1}	Return to labour US$ person-day^{-1}	Total labour cost US$ ha^{-1} day^{-1}	Net revenue US$ ha^{-1} year^{-1}
Chema							
Climbing bean 'smaller'	1247	701	546	874	0.62	1543	-997
Climbing bean 'bigger'	2586	469	2117	1898	1.12	3352	-1235
Maize/bush bean	617	136	482	233	2.07	412	70
Banana	6569	0	6569	457	14.39	806	5763
Mpungu							
Climbing bean	801	199	602	1330	0.45	2802	-2200
Sorghum	308	4	305	791	0.39	1665	-1360
Banana	5478	0	5478	304	17.99	641	4837

Thousand seed weights used to calculate sowing rates (kg ha^{-1}) were conservative estimates from literature: bush and climbing bean, 400 g (Niringiye et al., 2005); maize, 420 g (Dixit et al., 2011); Sorghum, 30 g (Mwithiga and Sifuna, 2006).

Partial budget analysis of current climbing bean cultivation in comparison with other crops
Low labour requirements (mostly only weeding) in combination with high yields and relatively high prices for banana, resulted in high net revenues, high returns to labour, and high net revenues when labour was accounted for as a cost (Table 24). Net revenue of maize/bush bean in Chema was lower than that of climbing bean, mainly because maize/bush bean was cultivated only once a year. Due to the lower labour inputs for maize/bush bean however, returns to labour and net revenue (when labour accounted for as cost) were higher for maize than for climbing bean. Due to lower yields and lower prices for sorghum in Mpungu, total revenue of sorghum was lower than for climbing bean. Returns to labour however, were only slightly higher for climbing bean than for sorghum due to higher input cost and higher labour requirements for climbing bean. When labour was accounted for as a cost, profit was less negative for sorghum than for climbing bean. Calculating labour as cost, except for banana, always resulted in negative net revenue, hence labour intensive crops like climbing bean resulted in lower profits.

Variability in returns to labour
Returns to labour were highly variable(Fig. 24). Variation in yields between farms resulted in more variation in returns to labour in Mpungu than in Chema, which was mainly caused by some much higher yields that were obtained in a few fields in Mpungu. Differences in labour inputs gave considerable variation (in particular for 'smaller area' climbing bean fields in Chema), showing that labour input could differ strongly per farm and/or that farmers' estimates might not always be correct. Variation in price in the past five years seemed to result in less variation. Variation due to highest and lowest prices however, could still be considerable, >100% in Chema and around 70% in Mpungu for annual crops. Bigger variation in Chema than in Mpungu was mainly due to the bigger variation in crop price in Chema (Annex II).

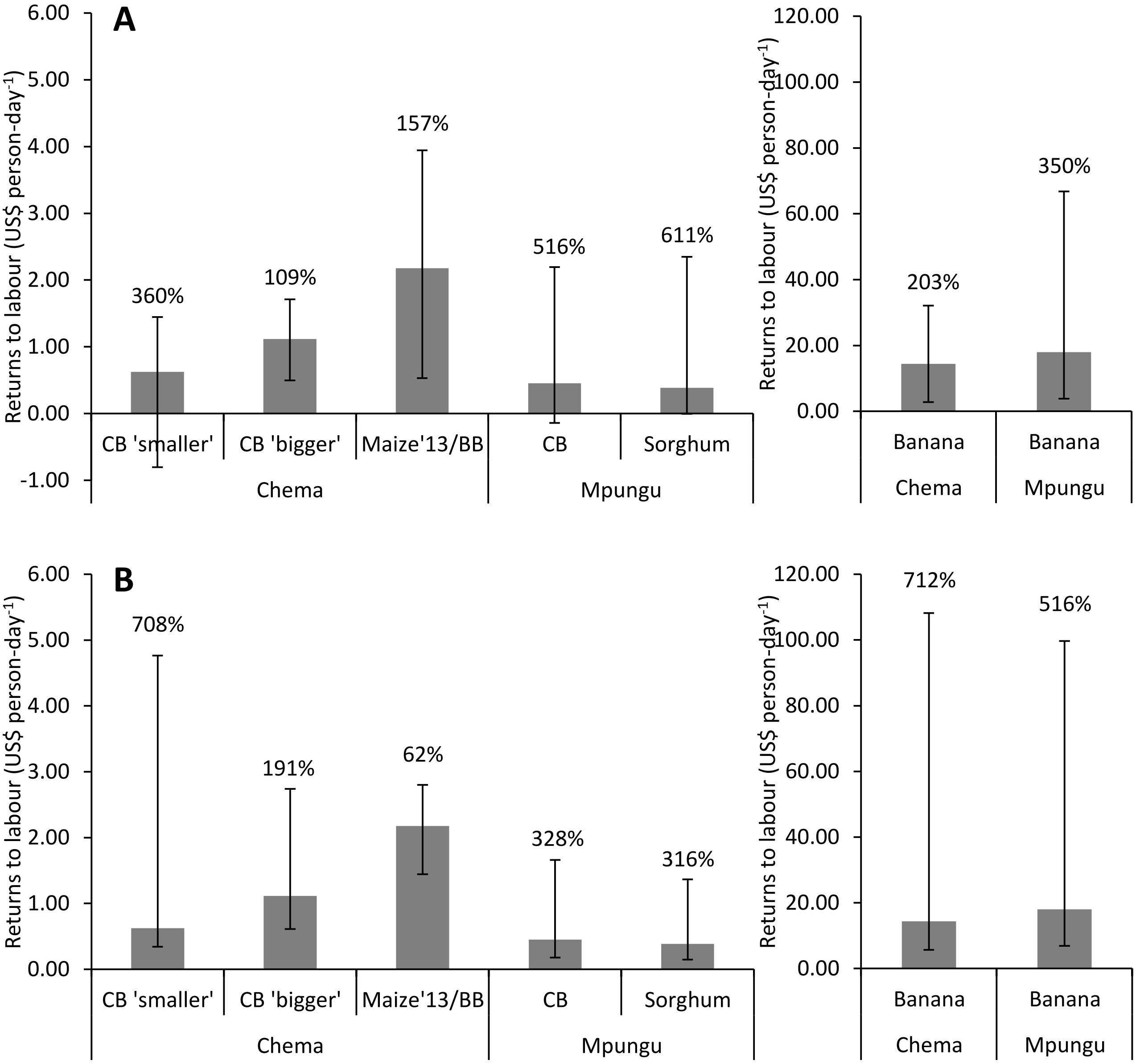


Fig. 23. Returns to labour and the effect of variation of farmers reported yield (A) and labour input (B). Error bars represent the variation in returns to labour as a result of the highest and lowest farmers'yield and farmers' reported labour input. Percentages shown above the error bars represent the total difference in returns to labour due to highest and lowest returns to labour as related to the average returns to labour.

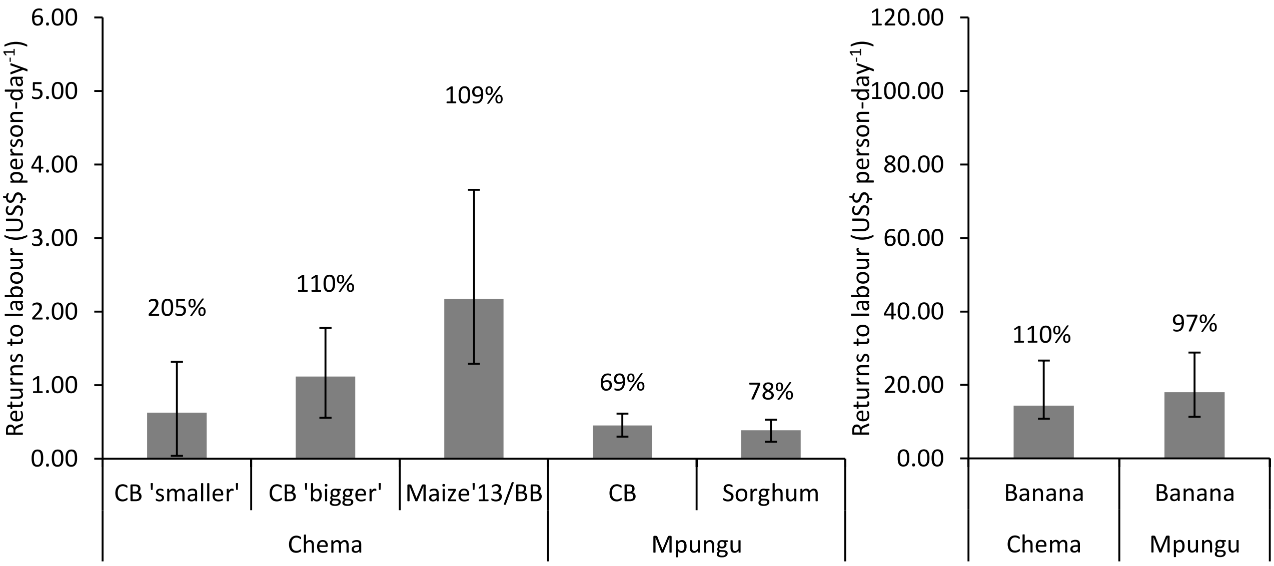


Fig. 24. Returns to labour and the effect of variation of farmers reported highest and lowest crop prices in the past five years. Error bars represent the variation in returns to labour as a result of the highest and lowest price. Percentages shown above the error bars represent the total difference in returns to labour due to highest and lowest returns to labour as related to the average returns to labour.

6 Discussion

6.1 Characteristics of current farming systems

Constructing farm typologies

Farm typologies were developed using similar characteristics for both Chema and Mpungu and using similar characteristics as used by Tittonell et al. (2010). Difference in market access and cultivated area between Chema and Mpungu however, seemed bigger than differences between sites studied by Tittonell et al. (2010) in western Kenya and eastern Uganda. Differences between Chema and Mpungu required different ranges per farm type per characteristic in Chema and Mpungu and resulted in not all farm types being present in both sites. This emphasizes that although certain patterns in farming systems might be recurring in different sites, local differences should not be overlooked (Giller et al., 2011). Different ranges per farm type for different areas could result in a need to provide different options for similar farm types (e.g. having similar production objectives and sources of income) across different areas.

The use of a RFC-survey to develop farm typologies showed to be a sufficient and effective method. Only one household did not fit in its initially assigned farm type (based on the RFC survey) and characteristics assessed in the DFC showed similar differences between farm types as assessed in the RFC, which was in line with findings from Van den Brand (2011) and Reckling (2011). Discussing a draft farm typology with several resource persons and purposely selecting additional households in Mpungu was an effective method to include all relevant variation, including farmers which only form a small proportion of the total population. Random selection of a larger number of households (50-100) for the RFC would however still be preferred for a better estimation of the distribution of households among farm types and to gain an overview of other characteristics of the farming systems.

Cultivated area and crop cultivation

The systematic differences in farmer estimated land owned in the N2Africa baseline survey (RFC) and measured area in the DFC in Mpungu pointed out the need to carefully consider the differences between local farmer used units and researcher used units if one wants to rely on farmer estimates for further analysis. Overestimation of cultivated area in Mpungu might be caused by overestimating the area of mostly small plots as was also found by Carletto et al. (2011) Overestimations however, can also be caused by the conversion factor used from local units to acres. Farmers not reporting their less important fields or fields further away during interviews, might a be reason why cultivated area was underestimated in Chema.

Small farm and plot size in particular in Mpungu (average plot size: 0.05, 0.06 and 0.09 ha for FT1, FT2 and FT3 respectively) might influence possibilities for development (through agriculture). Carletto et al. (2011) and Carletto et al. (2013) found higher yields for smaller plots than for bigger plots in Uganda (i.e. the inverse farm size-productivity relationship). Small farm and plot size might therefore be more beneficial for total food production of a region (Carletto et al., 2011). This might however be more a short term solution and not help farming households out of poverty. Small farm size often results in too low total farm production to reach food self-sufficiency and to reach a daily income of $1.25 per person (Harris and Orr, 2014; Hengsdijk et al., 2014), this can be a source of hidden poverty (van Vliet et al., 2015), and therefore, result in difficulties to adopt technologies for sustainable intensification (Vanlauwe et al., 2014a). In this study however, climbing bean yields were more related to cropping system than field size: lower climbing bean yields (ha^{-1}) were found on plots with 'smaller area' climbing bean cultivation using intercropping, which was generally practiced on smaller fields.

Soil fertility

Not only market access (hypothesised), but also soil fertility was considerably better in Chema than in Mpungu. High activity clays present in Luvisols in Chema positively influenced soil fertility indicators and resulted in relatively high OC, Ca and Mg contents. Luvisols are regarded as very suitable for agricultural production (Driessen et al., 2000). The negative trend between OC and clay fractions has also been described by others in relation to high activity clays and is not yet fully understood (Feller and Beare, 1997). Acrisols as present in Mpungu are associated with a range of adverse chemical soil properties, namely low pH, low base saturation, and (related to low pH) low quality organic matter. Furthermore, there is a risk of Al-toxicity and strong P-sorption in Acrisols, resulting in poor conditions for crop production (Driessen et al., 2000). High OC contents found in Mpungu in this study were similar to findings by Twongyirwe et al. (2013) for farmland around the adjacent Bwindi Impenetrable National Park, which was converted from forest. Nearby forest had similar OC contents as these farmlands, which points at slow mineralization of OC. Slow OC mineralization can be due to low pH (Hardon 1936 as cited in Janssen 2002).

The lower available cations (Ca, Mg and K) in Mpungu than in Chema, can be related to lower pH in Mpungu (Driessen et al., 2000; Fairhurst (ed.), 2012). In particular K showed critically low levels in Mpungu (median for all fields: 2.7 $mmol_{(+)}$ K kg^{-1}). Common bean needs a minimum of 5 $mmol_{(+)}$ K kg^{-1} (Anderson 1973 as cited in Amijee and Giller 1998) and crop cultivation in general 2.0 $mmol_{(+)}$ K kg^{-1} (Fairhurst (ed.), 2012). 14 out of 18 climbing bean fields in Mpungu were below this threshold of 5 $mmol_{(+)}$ K kg^{-1}. Low available K for common bean can result in poor N_2-fixation and reduced crop growth (Amijee and Giller, 1998). Intercropping climbing bean in banana, as was done in Chema, can be an option to utilize the soils with highest available K in Mpungu, suitable for climbing bean.

Low pH in Mpungu (half of all fields <5.0, quarter <4.6) could result in low N and P availability (Fairhurst (ed.), 2012). N_2-fixation in common bean is often reduced in fields with pH <5.5, probably due to the low availability of other nutrients like P in acid soils (Munns et al., 1977).

Finally, available P (Mehlich III) in Chema (median 9.2 ppm) and Mpungu (median 4.5 ppm) was well below critical levels (12-15 ppm) as described for maize (Wendt, 1995; Snapp, 1998). Such low levels of available P could affect both yield and N_2-fixation as described for common bean in Malawi (Snapp et al., 1998). Low pH, low mineralization rates of soil OC and in particular low availability of K and P are therefore likely to result in poor crop growth in Mpungu in general and for common bean in particular, which affect the possibilities for improved (climbing bean) cropping options.

The described strong soil fertility effects in Chema (mostly positive) and Mpungu (negative) can be the reason why soil fertility indicators, apart from FT4 in Mpungu, did not differ per farm type as was found by Tittonell et al. (2005b) in western Kenya. Tittonell et al. (2013) however, also found no relation of soil fertility indicators to farm type in eastern Uganda and other areas in western Kenya. They found that farmers' estimated soil fertility class and distance to the homestead was related to available K, Ca, Mg and pH level. In Mpungu this was only the case for walking distance and available K, Ca, Mg and pH level and in Chema available P and K. Farmers' estimated soil fertility class was not, or only slightly (Chema) related to chemical soil fertility indicators. Highest levels of soil fertility indicators were found mostly in banana or banana/coffee fields and can be related to the reported application of manure, ash and household waste to fields close to the homestead. Such relations were also described by others (Tittonell et al., 2005a; Zingore et al., 2007b; Tittonell et al., 2013) and could indicate that a more evenly spread application of fertilizers over different fields could result in higher total farm yields (Zingore et al., 2011). More research would however be needed to generate such an advise as more evenly spread fertilizer application does not always result in higher total yields. Furthermore, detailed organic fertilizer availability and the effects of (combined) organic and inorganic fertilizer application on yields in Mpungu in different types of fields are not yet known.

The fact that no relation between soil fertility indicators (other than available P and K), and walking distance was found in Chema, was most probably related to the presence of fertile Luvisols in Chema. Higher Ca and Mg availability in maize/bush bean fields in Chema was most probably related to their lower position within the landscape. Landscape related patterns of soil fertility were also found by Ebanyat (2009) for lowland areas of Uganda. Poor soil fertility indicators for tea in

Mpungu might be related to continuous cultivation on these fields and might be less problematic for tea than for other crops as tea can withstand a low pH (Driessen et al., 2000). Higher OC values in tea fields were also found by Twongyirwe et al. (2013) and could be a result of less tillage and low pH in tea fields.

Analysing crop yields

As hypothesized, the type of cultivated crops differed per farm type. The relation observed between farm type and number of different crops cultivated was also found by others (Reckling, 2011; Van den Brand, 2011). Access to and use of inputs like inorganic fertilizers, crop protection agents and improved varieties was, as hypothesized, lower in Mpungu than in Chema.

Cropping systems in both Chema and Mpungu were complex, increasing the difficulty of assessing yields. Complexity included the use of mixtures of annual and perennial crops, long duration maize crops (nearly two seasons) and the use of mostly mixed cropping for both types of beans in Chema. In Mpungu small plots were cultivated with a high number of different crops, including different types of perennials. Although bush bean was cultivated on (in total) a larger area of the farm in Chema (one-third of the farm), it was mostly intercropped (more than 50%) and scattered over several fields, probably resulting in errors of farmers' reported yields. Earlier DFCs were conducted in maize dominated systems (e.g. Tittonell et al. 2010; Tittonell et al. 2005a; Tittonell et al. 2005b; Van den Brand 2011), or common bean dominated systems (Reckling, 2011). Others, assessing complex home garden systems in Ethiopia, measured total biomass of different crops to assess percentage intercropping (Negash, 2013), or compared average yields of distinct cropping systems and not yields between fields (Abebe, 2005). The low number of sampled farmers and fields, the researcher estimated percentage intercropping and farmers´ reported yields might have increased variability in yields.

Correcting for percentage intercropping however, was an important step towards identifying explaining factors for crop yield, as corrected yields were more closely related to factors like pest and disease score, farmers' soil fertility class, and specific management for climbing bean. Correlations found between yield and management and environment were mainly used to triangulate and explain other findings. Soils in Mpungu for instance were found to be poor based on soil sample analysis, which reflected the soil type and supported the finding that higher yields were only found in combination with a higher farmers' soil fertility score. Poor soil fertility was therefore regarded as an important factor affecting crop yields in Mpungu. Similarly, high scores for pest and disease incidence seemed to be related to low yields of climbing bean and sorghum in Mpungu. As pest and diseases were also a reason for most farmers to reduce the cultivated area of these crops and were reported as the most important constraint, pest and diseases were also regarded as an important factor explaining low crop yields in Mpungu. In Chema no overriding factors affecting annual crop yields were found. Although high pests and disease score seemed to influence yields, this was not mentioned in other parts of the DFC. Higher yields for fields closer to the homestead were only found for bush bean in Chema and climbing bean and sorghum in Mpungu. This repetitive pattern could be related to the more favourable soil fertility indicators closer to the homestead. The unexpected positive relation between climbing bean yields and walking distance in Chema, was possibly related to different types of climbing bean cropping systems as discussed in the following section.

Farm types showed no differences in yields in both Chema and Mpungu, which was not in line with the hypothesis and in contrast to earlier DFCs in east and central Africa (Tittonell et al., 2005a; Tittonell et al., 2010; Reckling, 2011). Poor soils and high pest and disease pressure could be overriding possible yield differences between farm types in Mpungu since nor 'poorer' neither 'better-off' farm types were using crop protection agents or, apart from tea, inorganic fertilizers. The difficulty of comparing plot yields and the apparent good soil fertility in Chema, could be reasons why no differences in yields between farm types were found in Chema. Including accurate annual yield estimates or measurements for the important perennial cash crops (banana and coffee in Chema, banana and tea in Mpungu) could help to reveal differences between farm types and yields and also allow for analysing differences in year round food self-sufficiency. Year round banana and coffee yields in combinations with year round annual crop yields, would also allow using land equivalent ratios to assess differences in yields on field level in the highly important home garden fields.

6.2 Factors explaining current climbing bean cultivation

Current climbing bean cultivation showed considerable variation between Chema and Mpungu. Also within Chema, two distinct climbing bean cropping systems were identified. The history of climbing bean cultivation, biophysical constraints, availability of inputs and variation in management were factors shaping climbing bean cropping systems in Chema and Mpungu and will be discussed in the following sections.

Area of climbing bean cultivation

The higher prevalence of climbing bean cultivation in Mpungu than in Chema goes against the hypothesis. The introduction of climbing bean in Chema taking place less than ten years ago resulted in a diverse and still developing climbing bean cultivation. Although climbing bean was only introduced in the 1970s in nearby Rwanda (Sperling and Muyaneza, 1995) and has spread since then, answers about climbing bean cultivation like 'since I was born' or 'as long as I can remember', showed how climbing bean was seen as an integral part of the farming systems in Mpungu.

Climbing bean cultivation was related to the importance of it for different farm types and the production objectives of different farm types. As hypothesised, total area of climbing bean per household was bigger for 'better-off' farm types than 'poorer' farm types in both areas, which was however mostly related to the finding that 'better-off' farm types also cultivated more land. The importance of climbing bean as a food or staple crop in Mpungu and the bigger percentage of the farm cultivated with climbing bean by 'poorer' FT1 and FT2 than by 'better-off' FT3 and FT4 showed the importance of climbing bean for 'poorer' farm types and might be related to their production objective (own consumption). Considerable differences between climbing bean cultivation assessed in the RFC of Mpungu and the DFC might be caused by the different seasons in which the assessments were conducted, inaccuracy of field size estimates in the RFC, and that climbing bean intercropping in banana gardens was recently prohibited.

The two types of climbing bean cultivation practiced in Chema seemed to be influenced by production objectives as well. 'Bigger area' climbing bean cultivation in Chema was more a commercial practice for 'better-off' farm types with the objective to sell most of their produce, not practiced by 'poorer' farm types,. 'Smaller area' climbing bean cultivation was however much more common, practiced by all farm types and mostly for own consumption.

Adoption of cropping systems

'Smaller area' rather than 'bigger area' climbing bean cultivation was most prevalent in Chema, which was similar to the central and western highlands of Kenya where climbing bean also had been introduced recently (Paut, 2013; Ramaekers et al., 2013). Prevalence of 'smaller areas' was most probably caused by shortage of land around Chema and shortage of staking material. The percentage of households cultivating climbing bean in Kenya however, was much less than in Chema (Paut, 2013; Ramaekers et al., 2013). Ramaekers et al. (2013) found that climbing bean was cultivated more by households having more land whereby it was not replacing other crops and grown as an additional crop. The importance of climbing bean and the type of adoption in Mpungu was similar to Rwanda where pure stand cultivation is also most popular (Sperling and Muyaneza, 1995; Musoni et al., 2005; Ruganzu et al., 2014). Similar to Rwanda, climbing bean almost completely replaced bush bean in Mpungu as bush bean was more susceptible to pest and diseases like root-rot.

Management factors affecting climbing bean yields

Not farm types (as hypothesized) but climbing bean cropping systems in Chema and soil fertility and pests in Mpungu seemed to be the most important factors influencing climbing bean yields, making these factors also most important to consider for 'best-fit' options. Yields in Chema were considerably lower in 'smaller area' fields (average 1021 kg ha^{-1}) than in 'bigger area' fields (average 2113 kg ha^{-1}). Uncorrected climbing bean yields in intercropped fields ('smaller area fields') in Chema were very similar to bush bean yields, which could be discouraging for adoption of the more labour intensive climbing bean cultivation. The variation in management in 'smaller area´ fields (plant and stake density, stake length), resulting in low and some higher yields, might be partly caused by the lack of experience and the 'learning-by-doing' climbing bean adoption in Chema (as opposed to learning from demonstrations etc.). Klapwijk (2011) found more variation in management with 'poorer' than with 'better-off' farm types in northern Rwanda. Since 'bigger area' fields in Chema were not cultivated by 'poorer' farm types and 'bigger area' fields showed better crop management than 'smaller area' fields, crop management could still differ per farm type.

Management factors that often influence climbing bean yields (staking density and stake length), and which were found to differ per farm type by Reckling (2011) and Klapwijk (2011), only resulted in highest stake density for FT3 in both areas and highest stake length for FT3 in Chema. That FT3 invested most in staking could be related to its production objective of producing (partly) for the markets. Poor plant growth due to poor soil fertility in Mpungu might be the reason why shorter stakes were used in Mpungu than in Chema and why they were shorter than found by others (Klapwijk, 2011; Reckling, 2011). Tallest stakes were found for the three most fertile fields with highest yields in Mpungu. Farmers therefore seem to be aware of the potential for taller stakes in more fertile fields.

Higher plant densities were related to higher yields and planting densities were highest for FT3 in both areas. Average plant densities (Chema, 210,000; Mpungu, 280,000 plants ha^{-1}) were considerably higher than recommended sowing densities in N2Africa demonstration plots (80,000 plants ha^{-1}). Higher sowing densities have been used by others: 111,111 plants ha^{-1} (Niringiye et al., 2005) and 200,000 plants ha^{-1} (Musoni et al., 2014). Trials to determine optimum sowing densities in Colombia also resulted in an optimum of 200,000 plants ha^{-1} (Francis et al., 1978). There might thus be reason to reconsider recommended sowing densities as shown in N2Africa demonstrations.

The relations between grain yield and stakes ha^{-1} in both areas and in Chema between stake length and grain yield were not significant, while Reckling (2011) found significant relations. Although yield was related to stake length in Mpungu, this was cofounded with soil fertility. The low number of 'bigger area' climbing bean fields and the high percentages intercropping in 'smaller area' fields (resulting in more unexplained variation) might be the reason why no significant relations were found for these factors in Chema. Poor soil fertility and pests might have reduced the effects of improved management on yield in Mpungu.

No relation was found between yield and planting or staking date as highest yields were only found for the most common planting and staking dates and there was only limited spread between these dates. Assessing planting and staking dates proved to be difficult which might be why no strong relations were observed.

Soil fertility and climbing bean yields

Soil fertility had important effects on climbing bean yields in both areas. The interaction between lower yields with increasing clay fractions and decreasing OC contents in Chema pointed at the risk of erosion of the eluviated top soils in Luvisols, after which the illuviated clay rich subsoil remains (Feller and Beare, 1997; Driessen et al., 2000). Increasing organic matter content can result in increased soil physical quality in these heavy clay soils and therefore result in better plant growth (Driessen et al., 2000; Dexter, 2004). Erosion control to maintain OC rich top soils and organic fertilizer inputs can thus be important options to maintain current good soil fertility in Chema.

The optimum or minimum of total N that was needed for relatively good yields in both areas (around 0.4% N) might be explained by the need for starter N to enhance N_2-fixation (Giller, 2001) and the generally moderate N_2-fixation of common bean (Giller, 1990). Applying small amounts of N fertilizers at planting can therefore be beneficial for climbing bean yields (Fairhurst (ed.), 2012). The earlier explained multiple deficiencies and low levels of available P, K and pH can be why no relations were found between grain yield in Mpungu and availability of these soil fertility indicators. Only if all indicators were higher, C:N was favourable and management was good, higher yields were obtained (three highest yields). Yields in Mpungu were also lower than farmers' reported yields in the Kabale region (1000-1600 kg ha^{-1}) (NARO, 2012), which might be caused by the poorer soils in Mpungu than around Kabale.

Although available P was well below critical levels, no effect of fertilizer application on climbing bean yields was found in both farmers' fields and N2Africa demonstrations in Chema. Further research would therefore be needed on other (micro) nutrient deficiencies or possible toxicities limiting climbing bean growth.

Input constraints

As hypothesised, stakes and the labour needed for staking seemed the most important input constraint in Chema. Issues arising from the overexploitation of local 'resource use agreements' by taking live materials like stakes from Mount Elgon National Park were already predicted by Sassen and Sheil (2013). With the postponement of a new 'resource use agreement' this became true, resulting in an increased shortage of stakes at the time of research. Promoting climbing bean technologies without providing options for alternative staking methods would therefore not be advisable. The high prices of stakes in Chema can be another reason to (further) test trellises as 'best-fit' options to reduce the need for stakes. In Rwanda, Musoni et al. (2014) found trellises a more profitable option than single staking technologies, with only slightly decreased yields for trellises. Availability of inorganic-fertilizers was still seen as a constraint in Chema, which points at the difficulty of accessibility, in particular for 'poorer' farm types who had least cash available.

Since pest and diseases and 'reducing soil fertility' were the overriding constraints in Mpungu, other factors were less often mentioned. No methods to control mole rats (*Tachyoryctes splendens*) were currently known. The farmer-reported preference of mole rats for certain climbing bean varieties was also described by Breure and Kool (2014) and might give opportunities for testing the susceptibility of different varieties to mole rat incidence. Another option that would require further research is to plant *Tephrosia vogellii* (Hook.f.) in farmers' fields to poison or expel mole rats as was described by Wortmann et al. (1998) for central Uganda. Others mostly refer to options as flooding of the burrow system or snare traps, to control mole rats (Fiedler, 1994).

Decreasing yields of cv. Mubano (also known as Umubano, Nabe 10c and G2333) can also be caused by cv. Mubano's susceptibility to vascular wilt (which seemed similar to the farmers' reported 'die back'), resulting in the abandonment of this variety in Rwanda (Buruchara and Camacho, 2000; Musoni et al., 2010). As Sperling and Muyaneza (1995) advised, the introduction of not only one but several new varieties could provide options for farmers to spread risks and to find the most appropriate varieties for local biophysical conditions and (market) preferences. As cv. Mubano had replaced all other varieties since 2007, new varieties can spread fast, also to 'poorer' farm types, which was also described by David and Sperling (1999). Seeds however were seen as difficult to obtain and the use of own saved seeds was common in Mpungu. Markets for (climbing bean) seeds might be less developed in Mpungu than in Chema and introducing new varieties in Mpungu would still require extra attention.

Available cash and labour

The lower revenue from farming activities for 'poorer' farm types than for 'better-off' farm types in both regions was in line with the hypothesis and was also found by others (Tittonell et al., 2005b; Van den Brand, 2011). High costs for labour inputs, and possibly overestimating these, might have resulted in the more negative yearly household balances for 'better-off' farm types but the latter also showed that 'better-off' households depend more on external labour than 'poorer' farm types. More external labour inputs were needed due to their higher land to labour ratio (family labour only). Based on absolute labour availability throughout the year, FT1 might be most constrained by labour for own cropping activities. The labour constraint for 'poorer' farm types to adopt new legume technologies that take more labour inputs was also described by Van den Brand (2011). Low or lower labour requirements for new climbing bean technologies would thus be important, in particular for ‘poorer’ farm types, a need that is often observed when developing new (legume) technologies in SSA (Giller et al., 2006; Vanlauwe and Giller, 2006).

The higher labour demand of climbing bean in comparison with other crops was considered less important in Mpungu as climbing bean was seen as such an important crop for food security. Although climbing bean is often found to require more labour than other crops like maize (Reckling, 2011), still there seemed to be an overestimation of labour demand for climbing bean in comparison with the study of Reckling. This overestimation might well represent the prevailing opinion (of farmers) that climbing bean has a very high labour demand. Since climbing bean also often required more (cash) inputs than other crops, ‘best-fit’ options for climbing bean cropping systems should try to minimize the use of these inputs, in particular for ‘poorer’ farm types.

Profitability of current and improved climbing bean cultivation

Overestimation of labour inputs for climbing bean cultivation can be one of the reasons why climbing bean showed low returns to labour compared with other crops. Even with improved management of climbing bean, maize/bush bean cultivation still had higher returns to labour than climbing bean. The bigger increase of returns to labour with improved management of ‘smaller area’ than ‘bigger area’ climbing bean cultivation was mainly caused by the highly variable (poor) management of ‘smaller area’ climbing bean fields. The proportionally larger increase in yields for ‘smaller area’ climbing bean cultivation can therefore result in a bigger increase in returns to labour than for ‘bigger area’ climbing bean cultivation.

That climbing bean resulted in the most negative net revenue was mainly caused by the high costs for material and labour inputs needed for climbing bean in comparison with other crops. The highly negative net revenue, when labour was accounted for as cost, for all annual crops could be caused by the overestimation of labour inputs and the high costs of labour. Mugabo et al. (2014) also found that bush bean could be more or equally profitable as climbing bean due to its labour costs for staking. The need for high input use can thus be a major constraint for climbing bean adoption. The high total revenue and high yields for climbing bean in comparison with other annual crops however, can still be a reason to cultivate climbing bean for households that are land constrained and/or not labour constrained.

Banana cultivation was highly profitable in both locations when compared with annual crops, which might be partly caused by the measurement errors. Estimated banana yields were more than two times as high as average yields described by Wairegi et al. (2009) and Wairegi et al. (2010) for the eastern and south-western highlands in Uganda. Banana cultivation however, would still be highly profitable when banana yields would be reduced by a factor two or three to account for this overestimation. High profitability of banana cultivation was also found by others (Pender et al., 2006; Ruoff, forthcoming) and can for a small part be explained by the difficulty of assessing year round labour inputs for banana.

6.3 Exploring options for increasing climbing bean productivity

The options described in this study for the eastern and south western highlands of Uganda may not be best agronomic practices, but should be seen as ‘best’ or ‘better fit’ options. ‘Best-fit’ options belong to a ‘basket of options’ that that include different options that can fit for different types of farmers in a specific region to fit within their ‘socio-ecological niche’ (Ojiem et al., 2006; Giller et al., 2011). The ‘basket of options’ can therefore entail a range of options, where most options might not result in highest attainable yields, but are options that help farmers to have highest yields under their specific constraints (e.g. only space for climbing bean in banana garden).

Current climbing bean cultivation was only partly related to farm type and much more influenced by cropping system (Chema) or major overriding constraints (Mpungu). Therefore, it seemed more feasible to consider options that could fit for these cropping systems and constraints than to recommend options to different farm type. A distinction was made between current available options that were based on technologies that were already used in the areas (as described in the results section) and future options that were taken from literature and could also be (part of) 'best-fit' options. For future options however, more research is required as they have not been tested within the specific context of the eastern and south-western highlands of Uganda yet.

Currently available options – Chema

The described improved management options for Chema seemed viable as they were based on highest yields that were currently achieved and which were related to better management practices that were already used within the current farming systems. Demonstration yields were obtained in sole crop conditions and were therefore not comparable with (assumed possible) improved yields for 'smaller area' fields. Incorporating options for improved 'smaller area' climbing bean cultivation in N2Africa trials or demonstrations however, can result in a better fit for 'poorer' farm types as they only have limited land available. 'Smaller area' climbing bean cultivation is also most common as approximately 80% of the households cultivating climbing bean in Chema used this cropping system. Even though climbing bean itself would not result in high yields in these intercropping systems, yield should be analysed at field level, also considering the other crops present. Intercropping systems of banana, coffee and other crops were found to be highly profitable in the east-African highlands (Van Asten et al., 2011; Ntamwira et al., 2014). The integration of climbing bean in banana (-coffee) gardens can therefore be a good option for sustainable intensification of these intercropping systems. Bush bean could also be an important option to consider for improved intercropping systems as uncorrected bush bean yields and uncorrected climbing bean yields were similar. Bush bean could particularly fit for 'poorer' farm types as it requires less inputs (e.g. stakes, staking) than climbing bean. The estimated improved climbing bean yields, based on currently available options, for 'bigger area' fields seemed realistic and already within range of yields obtained in demonstrations and within the range of potential yields of these varieties, 2500-3500 kg ha^{-1} (NaCRRI, 2013).

Future options – Chema

Pruning intercropped banana, resulting in higher yields of climbing bean and no reductions in banana yields (Ntamwira et al., 2014), might be a viable option for 'smaller area' field in Chema. Introducing shade tolerant cultivars could also be an option to improve yields beyond the estimated improved yields. However, since the genetic base of climbing bean is small, crossing with other cultigens of *Phaseolus* would be needed to increase shade tolerance of climbing bean as described by Baudoin et al. (2001) for the Colombian highlands.

Other options that could support 'smaller area' climbing bean cultivation can be to grow *Leucaena* or *Calliandra* (which could also be incorporated in erosion control measures or planted as hedges) to produce some own stakes as is as practiced in Rwanda (Musoni et al., 2005; Klapwijk, 2011). Similarly, the earlier mentioned trellises could be an option as staking method that 'fits' for 'smaller area' climbing bean cultivation. The use of tripods, as demonstrated in N2Africa demonstrations around Chema, could fit well for 'bigger area' climbing bean farmers. Farmers growing 'bigger area' fields often target higher yields and might therefore need stronger staking methods than single staking. When strong stakes are scarce, the use of three or two weaker stakes in tripods could for example also result in a more durable staking method. Education on pest management would be another option to further increase yields for 'bigger area' climbing bean farmers as they might be more able to buy pest management inputs. The use of fertilizers needs further research as no short term benefits were found, while the use of both organic and inorganic fertilizers are an important component of sustainable soil fertility management.

Current or only future options? – Mpungu

Since highest yields were not only obtained with best management but mostly on good soils in combination with low pest and disease pressure in Mpungu, the three highest yields as shown for the 'potential' yield might not be within reach for most farmers and be more the result of what Tittonell et al. (2009) describe as a higher systems state. Liming, the application of P and K fertilizers and/or application of organic fertilizers would be first steps towards similar high yields as these best yields or yields obtained in demonstrations. Lime might be difficult to obtain in Mpungu, which is typical for ‘poor market access’ areas (Vanlauwe et al., 2014b). The effect of manure application on climbing bean yields in Mpungu (50% increase, not significant) showed that soils were not (all) unresponsive as described by Tittonell and Giller (2013). Manure is needed however as part of options to increase soil fertility, which results in a poor ‘fit for ‘poorer’ farm types who owned no or very little livestock and applied no manure to climbing bean. This vicious cycle of low access to inputs for poorest farm types, resulting in limited options for soil fertility improvement (of poor soils) and therefore very limited scope for yield improvements, is seen as a common ‘poverty trap’ for smallholder farmers in sub-Saharan Africa (Tittonell and Giller, 2013). Applying only a spoon-full of manure next to the planting hole could still be an option for half of the ‘poorer’ farmers who owned some small livestock like a goat or chickens. This practice can result in improved yields (Giller et al., 2013). Further research would be needed to test whether applying small amounts of manure in ‘poorer’ farmers’ fields in Mpungu would also increase yields. An option to target most fertile fields in Mpungu could be to intercrop climbing bean in banana gardens, further research however should reveal how this influences climbing bean yields and whether there are options to reduce the risk of spreading banana bacterial wilt.

Designing ‘best-fit’ options based on currently available options, in particular for ‘poorer’ farmers, is therefore likely to result in very limited yield increases. Only ‘best-fit’ options offered as a part of external interventions from the government or NGOs that include the provision or subsidy of options as pest (mole rat) control, new varieties, and that make lime and fertilizers available and accessible (also to ‘poorer’ farm types), are likely to result in considerably higher yields.

7 Concluding remarks

- Farm types only partly explained differences in current cropping systems. Only cultivated area of climbing bean and not yields differed per farm type. Climbing bean yields seemed most influenced by cropping systems in Chema and poor soil fertility and pest incidence in Mpungu. Farm typologies however, could still help to describe ‘best-fit’ options available for specific groups of households with similar resource constraints and production objectives.

- Average yields in Chema were 1019 kg ha^{-1} and 2113 kg ha^{-1} for ‘smaller area’ and ‘bigger area’ climbing bean fields respectively. Average climbing bean yields for Mpungu were 811 kg ha^{-1}, while management was similar as in ‘bigger area’ fields in Chema. Lower yields in Mpungu were mainly caused by poorer soil fertility, higher pest incidence and partly by the shorter cropping season of 2014A in Mpungu than in Chema.

- The variability in options needed to improve climbing bean production between Chema and Mpungu pointed at the importance of market access, pest and disease pressure and soil fertility for climbing bean cultivation.

- ‘Best-fit’ options based on currently used technologies were estimated to result in yield increases of 30-60% in Chema. Current options used in demonstrations fitted best for ‘bigger area’ cropping systems, which were mostly practiced by ‘better-off’ farm types. To provide options that could fit with the more common ‘smaller area’ cropping system, (which was also practiced by ‘poorer’ farm types) improved intercropping technologies (i.e. increased planting density and staking density) should also be tested. Furthermore, demonstrations itself might already help to improve farmers knowledge on appropriate crop management.

- Designing ‘best-fit’ climbing bean options based on technologies available within Mpungu would result in only limited effects on yields due to overriding constraints of poor soil fertility and high pest pressure. More important would be to increase the availability and accessibility of fertilizers, also for ‘poorer’ farmers, and to make lime and options for pest control available within Mpungu. Introducing new (resistant) varieties could further help to overcome some of the current constraints of climbing bean.

- Even though climbing bean had a higher total revenue, due to high input use it gave lower returns to labour than crops like maize/bush bean or sorghum. Improved management resulted in increased returns to labour for climbing bean, in particular for ‘smaller area’ fields in Chema.

- Climbing bean was cultivated by all farm types, also the ‘poorer’ (FT1 and FT2). ‘Poorer’ farm types however might find it most difficult to use improved technologies as these often require more inputs. Finding and offering options for climbing bean cultivation such as banana pruning in intercropping (Chema), trellises for staking (Chema), applying a spoon-full of organic fertilizers (Mpungu), and making fertilizers accessible (Mpungu), are important to reach this biggest group of households. These options however, would need further research as these have not yet been tested within the studied areas.

- Increasing (demonstrated) planting densities can be a viable option to increase yields for all farm types. Increasing the (soil nutrient) resource base however, should come from increased fertilizer inputs. Apart from increasing inorganic fertilizer inputs in Mpungu, further research should be conducted on the best distribution of organic fertilizers at farm and village level. The apparent lack of response to fertilizer inputs points to the need for further research to increase climbing bean yields in Chema.

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Annex I – Soil reference samples

Results of the soil sample analysis of 10 reference sub-samples originating from one thoroughly mixed sample.

Sub-sample #	pH 1:2.5 H_2O	OC % Walkley & Black	N % Kjeldahl	P mg/kg Mehlich III	Ca mmol/kg	Mg mmol/kg	K mmol/kg	Sand %	Clay %	Silt %
1	6.6	2.3	0.09	28.06	134.7	40.1	3.9	50	40	10
2	6.7	2.0	0.10	28.06	143.8	41.1	4.2	50	40	10
3	6.7	2.0	0.08	29.25	146.2	42.0	4.2	50	40	10
4	6.7	2.4	0.06	25.35	153.9	46.3	4.6	50	40	10
5	6.8	2.1	0.05	28.74	133.2	40.3	4.0	50	40	10
6	6.7	2.1	0.07	23.99	125.6	42.7	4.5	50	40	10
7	6.5	2.2	0.06	30.10	147.3	41.6	4.3	50	40	10
8	6.6	2.2	0.08	26.87	138.2	40.8	3.9	49	40	12
9	6.7	2.2	0.37[1]	27.21	136.9	40.2	4.3	49	40	12
10	6.7	2.0	0.05	30.27	142.1	43.3	4.3	49	40	12
Average	6.7	2.2	0.07	27.8	140.2	41.8	4.2	50	40	11
SE	0.03	0.04	0.01	0.64	2.58	0.61	0.07	0.31	0.00	0.31
CV	0.01	0.06	0.23	0.07	0.06	0.05	0.05	0.02	0.00	0.09

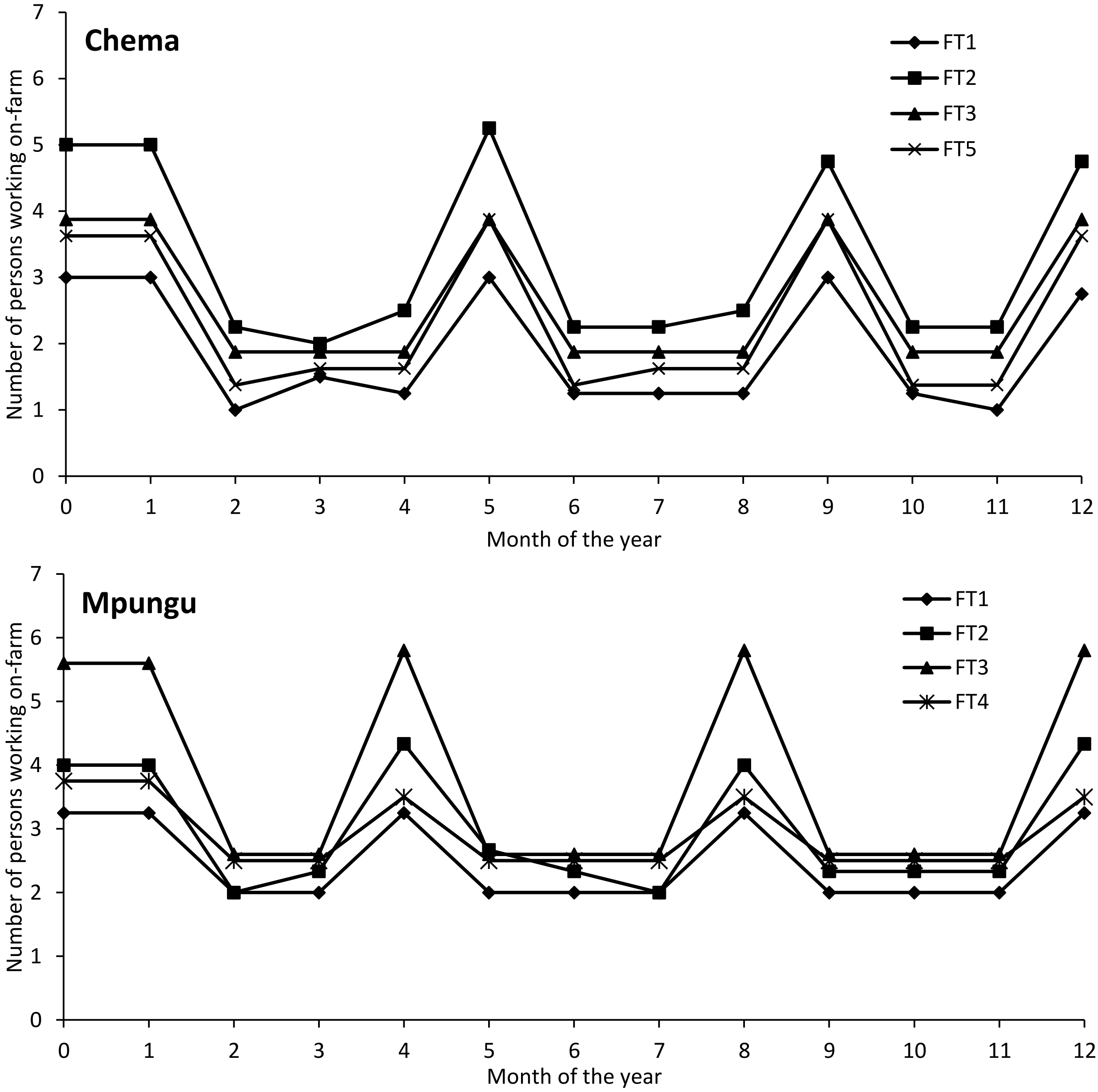
[1] The value for percentage N in sub-sample 9 was seen as an outlier and not considered to calculate the average, SE and CV.
SE=standard error of the average, CV=coefficient of variation.

Annex II – Price fluctuation of important crops

Price fluctuation in the past five years of most important crops in Chema and Mpungu. Average prices and the highest and lowest price of these crops (expressed as percentage deviation of the average price) are shown.

	n	Average price (US$)	Unit	Deviation of the average price (%)		
				Lowest price	Highest price	Total deviation
Chema						
Bush bean	15	0.64	kg	-36	+53	89
Maize	15	0.30	kg	-31	+63	94
Climbing bean	13	0.61	kg	-41	+49	90
Banana	13	3.51	Bunch	-25	+85	110
Coffee	12	2.47	kg	-53	+63	115
Mpungu						
Climbing bean	15	0.50	kg	-25	+27	52
Banana	14	2.69	Bunch	-37	+60	97
Sweet potato	12	0.08	kg	-44	+74	118
Tea	8	0.12	kg	-16	+20	36
Millet	7	0.47	kg	-18	+38	56
Sorghum	7	0.39	kg	-40	+37	77
Irish potato	3	0.17	kg	-24	+100	124
Coffee	2	1.92	kg	-40	+65	105
Cassava	2	0.20	kg	-28	+50	78

Annex III – Labour availability



Labour availability over the year for different farm types in Chema and Mpungu.

Annex III – Common crops rotations

Frequency and the percentage of fields that were cultivated in a typical crop rotation (annual crops) in Chema and Mpungu.

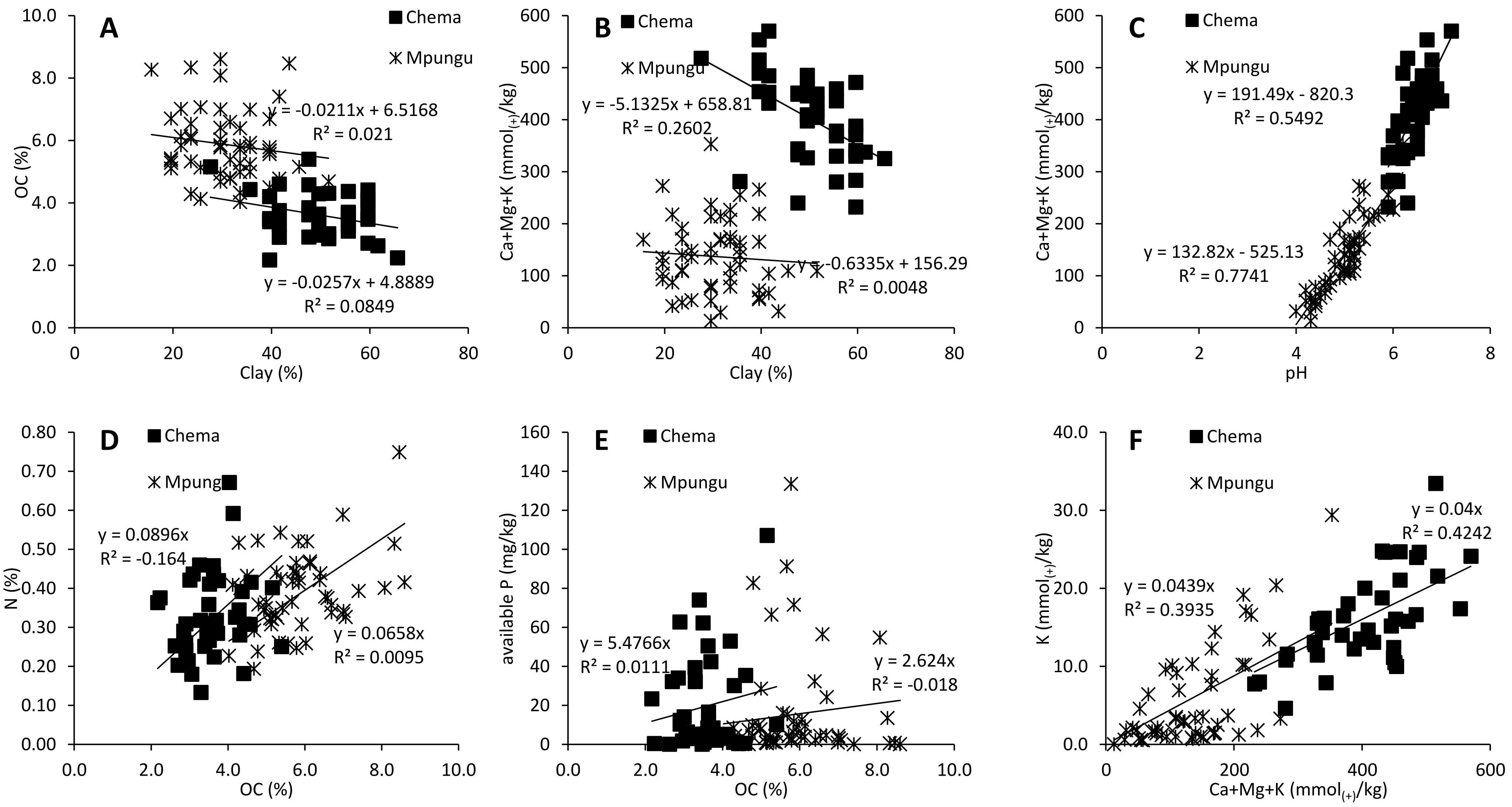
Chema			Mpungu		
Rotation	# fields	% fields	Rotation	# fields	% fields
Legume-legume	16	34	Cereal-cereal	15	20
Cereal/legume-cereal/legume	11	23	Fallow-cereal	14	19
Cereal-cereal	4	9	Cereal-tuber	8	11
Cereal/legume-legume	3	6	Cereal-legume	7	9
Cereal/legume-cereal	2	4	Banana/climbing bean	5	7
Other (new fields, rot. only once)	11	23	Legume-legume	3	4
			Banana/yam	2	3
			Tuber-tuber	2	3
			Legume-cereal	0	0
			Other (new fields, named only once)	18	24
Total # fields assessed on rotations	47			74	

/ = intercropping, - = sequence in time

Number of times that a crop was mentioned to have increased or decreased in cultivated area in the past three years. A maximum of three crops were asked for per category.

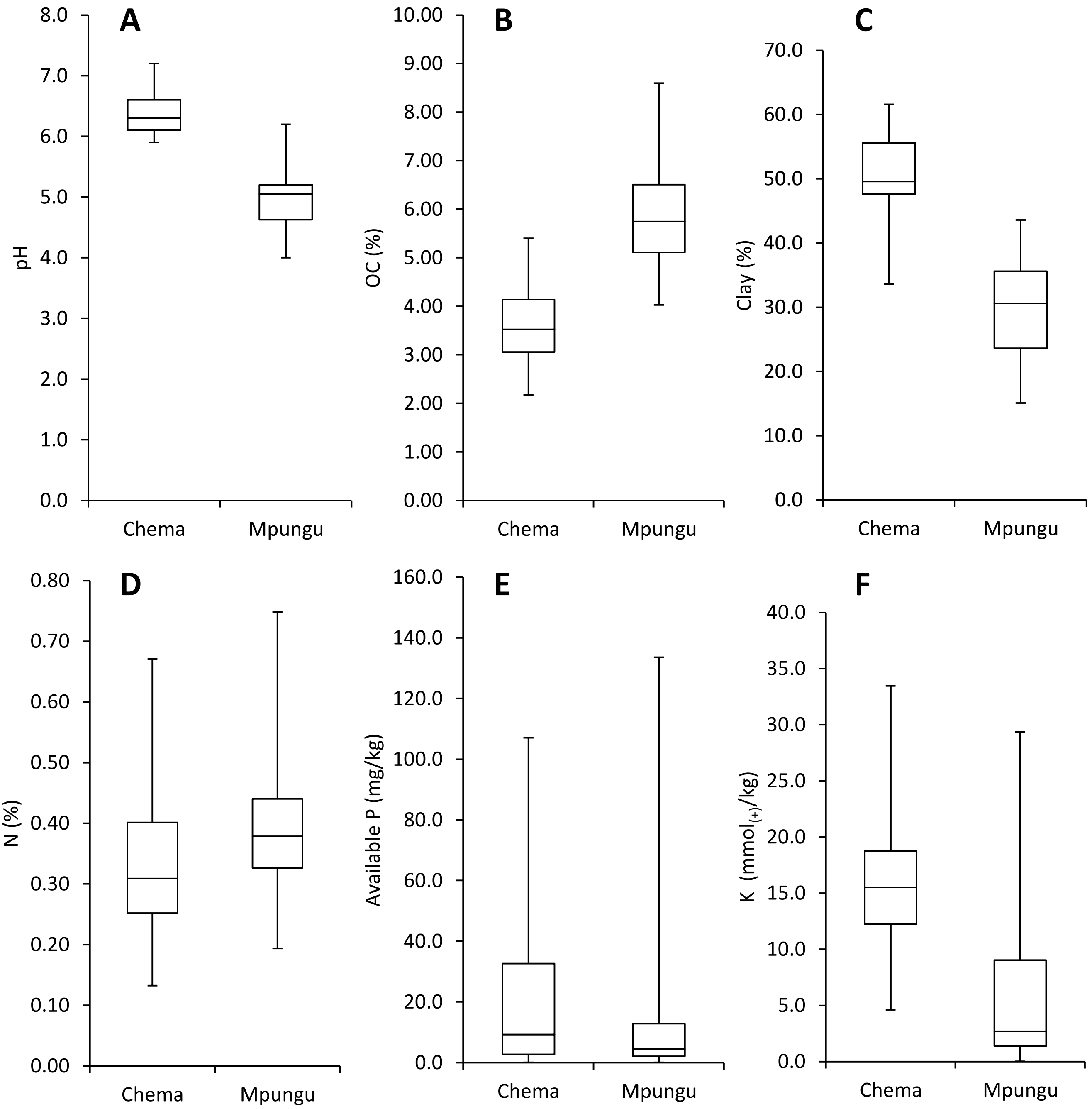
Increased		Decreased	
Chema			
Maize	4	Maize	4
Bush bean	4	Banana	4
Climbing bean	3	Coffee	4
Banana	2	Bush bean	1
Irish potato	1	Climbing bean	1
Total	14		14
Mpungu			
Sweet potato	9	Climbing bean	14
Banana	6	Sorghum	8
Cassava	5	Sweet potato	5
Maize	4	Banana	5
Yam	4	Irish potato	3
Millet	3	Millet	2
Climbing bean	2	Field pea	2
Irish potato	1	Maize	2
Trees	1	Rice	1
		Coffee	1
Total	35		43

Annex V – Relationships between soil fertility



Relationship between the OC fraction and the clay fraction (A), Ca+Mg+K and the clay fraction (B), Ca+Mg+K and pH (C), total N and the OC fraction (D), available P and the OC fraction (E), and available K and Ca+Mg+K (F) for fields sampled in Chema (*n* = 41) and Mpungu (*n* = 54).

Annex VI – Box and whisker plots for soil fertility



Box and whisker plots illustrating the variability in pH (A), OC (B), clay (C), total N (D), available-P (E) and K (F) for soil samples taken in Chema (*n* = 41) and Mpungu (*n* = 54).

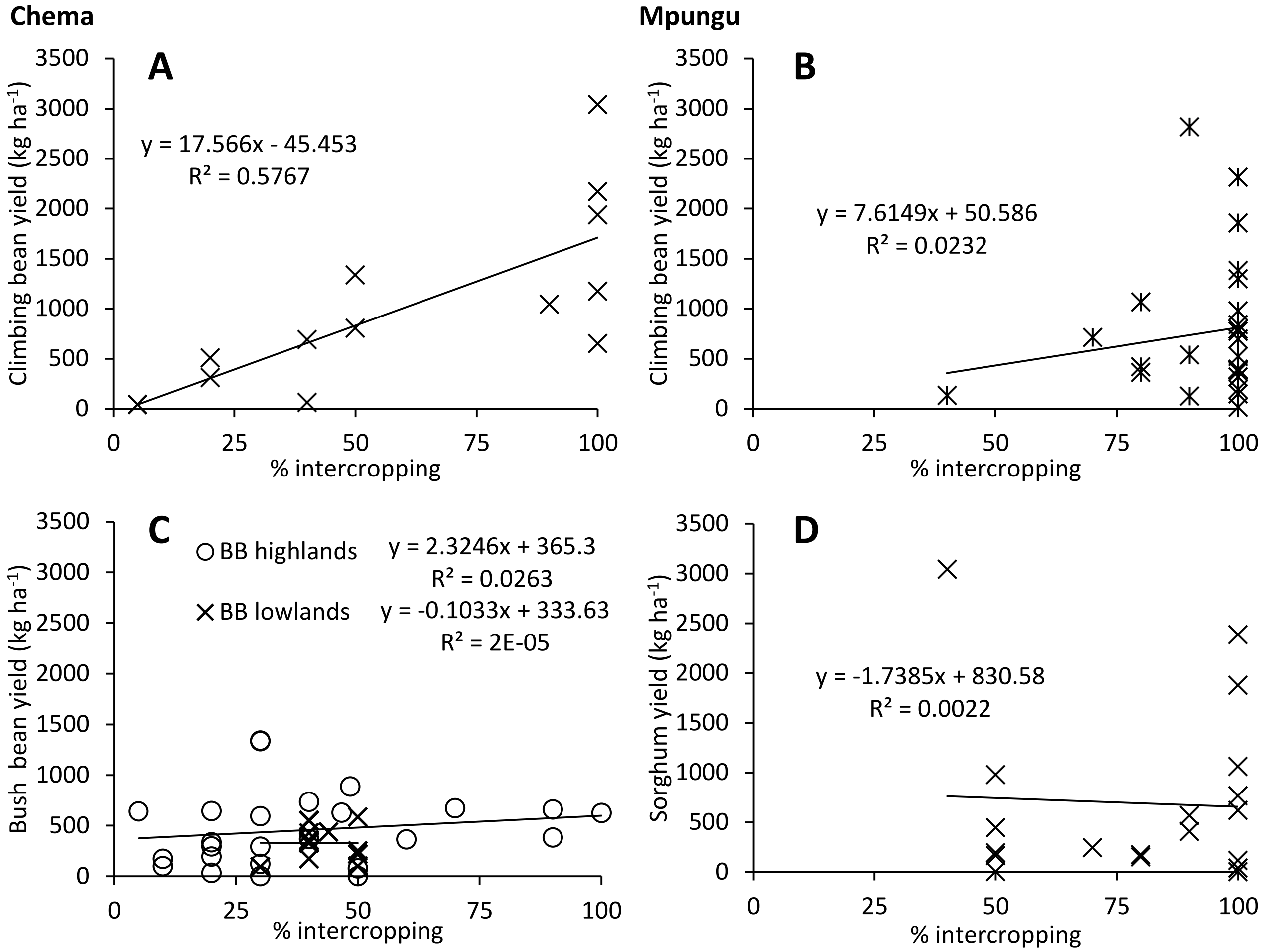
Annex VII – Soil fertility indicators as related to farmers' estimated soil fertility class

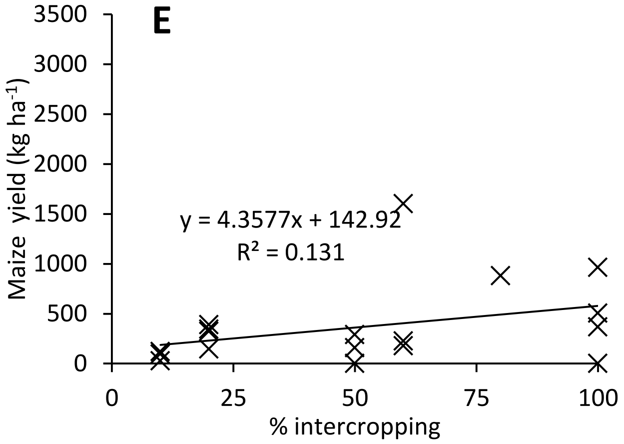
Soil fertility indicators as related to farmers-estimated soil fertility class in Chema and Mpungu. SE is given between parenthesis.

Soil fertility class[1]	n[2]	pH (-)	OC (%)	N (%)	Available P (mg/kg)	Ca ($mmol_{(+)}$/kg)	Mg ($mmol_{(+)}$/kg)	K ($mmol_{(+)}$/kg)	Ca+Mg+K ($mmol_{(+)}$/kg)	Clay (%)	C:N (-)
Chema											
Poor	6	6.3 (0.10)	3.7 (0.10)	0.29 (0.04)	9.4 (5.8)	215 (22)	127 (9)	15.2 (2.2)	357 (28)	52 (5)	13 (1.2)
Medium	17	6.3 (0.08)	3.7 (0.08)	0.38 (0.03)	17.4 (6.4)	239 (16)	129 (4)	15.1 (1.2)	383 (20)	51 (2)	10 (0.6)
Good	15	6.5 (0.09)	3.4 (0.09)	0.29 (0.02)	30.0 (6.6)	275 (17)	149 (4)	17.3 (1.8)	442 (21)	48 (2)	12 (0.7)
Mpungu											
Poor	10	5.1 (0.08)	5.9 (0.08)	0.38 (0.02)	9.0 (3.1)	89 (11)	50 (6)	4.3 (1.2)	143 (16)	32 (3)	16 (0.9)
Medium	17	5.0 (0.12)	5.9 (0.12)	0.38 (0.03)	19.2 (9.0)	82 (12)	50 (8)	5.5 (1.9)	137 (21)	31 (2)	16 (1.0)
Good	27	5.0 (0.10)	5.8 (0.10)	0.39 (0.02)	17.8 (4.8)	77 (7)	52 (6)	6.0 (1.1)	134 (13)	30 (1)	18 (3.4)

[1] Soil fertility class is the farmers' estimated soil class. [2] *n* is the number of fields

Annex VIII – Crop yields as related to percentage intercropping





Uncorrected climbing bean (A) and bush bean (C) grain yields for Chema and climbing bean (B), sorghum (D) and maize (E) grain yields for Mpungu as related to the percentage intercropping of these crops in a field.

Annex IX – Climbing bean cultivation according to the

Occurrence of climbing bean and importance of intercropping amongst different farm types in Chema (2014A) and Mpungu (2013B) as found in the RFC. Households cultivating climbing bean were grouped in households cultivating climbing bean on a 'smaller area' (<30 m2 or intercropping with <30% climbing bean) and households cultivating climbing bean on a 'bigger area' (>30 m2 and intercropping with > 30% climbing bean).

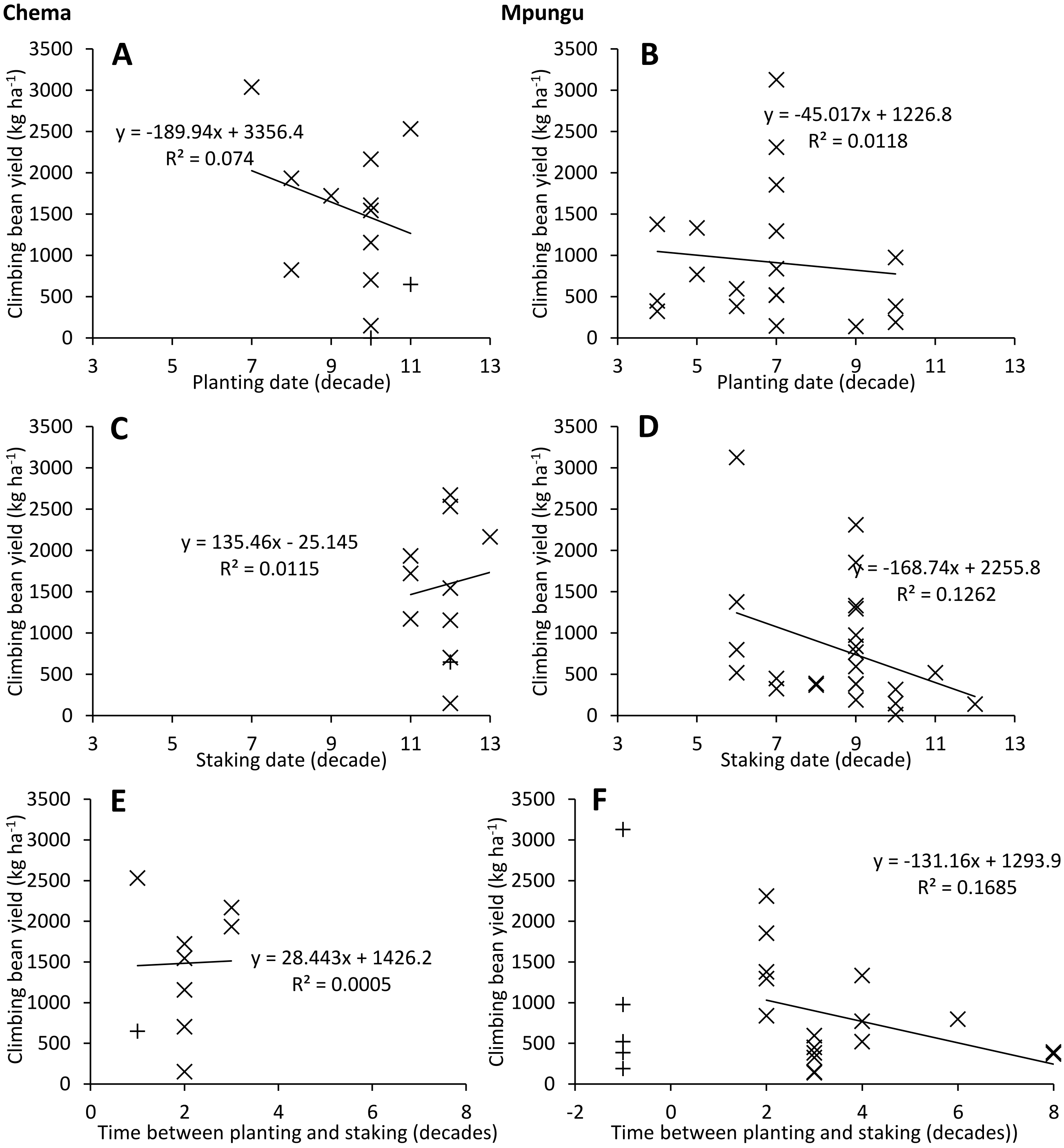
				HH cultivating a 'smaller area' of CB				HH cultivating a 'bigger area' of CB			
Farm type	Total # HH/FT	# households cultivating CB	% of HH cultivating CB	# HH	Average % CB in CB fields	CB area per farm[1] (ha)	% of the farm cultivated with CB[2]	# HH	Average % CB in CB fields	CB area per farm[1] (ha)	% of the farm cultivated with CB[2]
Chema											
1	14	9	64	8	14	0.04	10	1	37	0.11	28
2	30	19	63	17	12	0.05	6	2	50	0.07	10
3	12	7	58	3	13	0.13	5	4	83	0.19	10
4	-	-	-	-	-	-	-	-	-	-	-
5	18	15	83	14	16	0.07	6	1	55	0.04	18
Total	74	50		42				8			
Average			68		14	0.06	7		65	0.13	13
Mpungu											
1	9	7	78	2	25	0.02	14	5	100	0.09	56
2	11	5	45	1	25	0.05	25	4	88	0.08	33
3	5	4	80	1	30	0.01	1	3	100	0.15	50
4	4	3	75	0	-	-	-	3	100	0.30	8
5	-	-	-	-	-	-	-	-	-	-	-
Total	29	19		4				15			
Average			66		26	0.02	13		97	0.14	39

[1] $\text{CB area per farm} = \sum_{i=1}^{n} CB\%_{(i)} \times Area_i$

[2] % of the farm cultivated with CB = CB area per farm/total cultivated area per farm

HH=households, FT=Farm Type, CB=climbing bean.

Annex X – Climbing bean yields as related to planting and staking date



Climbing bean grain yields for all fields assessed as related to planting date (A and B), staking date (C and D) and time between planting and staking (D and E) in Chema (A, C, E) and Mpungu (B, D, F). Outliers (+) or negative values for time between planting and staking were not included for regression analysis.