Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Soil and Environment

Soil factors affecting plant performance of climbing beans (*Phaseolus vulgaris* L.) in south western Kenya

Hanna Williams

Degree project in Biology
Agriculture Programme – Soil and Plant Sciences

Examensarbeten, Institutionen för mark och miljö, SLU 2016:01

Uppsala 2016

SLU, Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Soil and Environment

Hanna Williams

Soil factors affecting plant performance of climbing beans (*Phaseolus vulgaris* L.) in south western Kenya
Markfaktorers påverkan på tillväxten av störbönor (*Phaseolus vulgaris* L.) i sydvästra Kenya

Supervisor: Sigrun Dahlin, Department of Soil and Environment, SLU
Assistant supervisors: Maurice Shiluli, Kenya Agriculture and Livestock Research Organization (KALRO), Kisii, Kenya; Irene Okeyo, World Agroforestry Centre, Kisumu, Kenya; Ingrid Öborn, World Agroforestry Centre, Nairobi, Kenya & Department of Crop Production Ecology, SLU
Examiner: Bo Stenberg, Department of Soil and Environment, SLU

EX0689, Independent project in Biology – bachelor project, 15 credits, Basic level, G2E
Agriculture Programme – Soil and Plant Sciences 270 credits (Agronomprogrammet – inriktning mark/växt 270 hp)

Series title: Examensarbeten, Institutionen för mark och miljö, SLU
2016:01

Uppsala 2016

Keywords: penetrometer resistance, soil pH, staking, CN ratio, Kisii, KALRO

Online publication: http://stud.epsilon.slu.se

Cover: Climbing bean at flowering stage, photo by author, 2015

Abstract

The south west part of Kenya is the most densely populated part of Kenya. This part of Kenya has relatively fertile soils and a favorable environment for crop production, which is why it is a major food producing area. The high population results in land scarcity with the average farm size ranging from 0.8-1.8 ha. Climbing beans (*Phaseolus vulgaris* L.) have the potential for higher areal yield than common beans, because of their indeterminate growth habit and ability to climb if being supported mechanically. This is the reason why the project Legume CHOICE introduced them in this area.

The aim of the study was to determine if certain soil factors in the area limit the performance of climbing beans. The soil factors studied were pH, penetrometer resistance, C and N concentration and CN ratio. The plant performance was measured by germination rate, plant height and growth stage at three occasions. The hypothesis was that a high pH, C and N concentration and CN ratio would have a positive effect on plant performance, and that a high penetrometer resistance, indicating soil compaction, would have a negative effect on plant performance.

Data were collected from 30 on-farm trials on three sites in Kisii and Migori counties. Soil samples for pH were taken in each plot, using a soil auger, and analyzed at the ICRAF lab in Nairobi. Soil samples for C and N analysis were taken according to the LDSF sampling technique and analyzed at the University of Hohenheim, Germany. Soil samples were taken for topsoil (0-0.2 m) and subsoil (0.2-0.5 m). Penetrometer resistance was measured in five places in each plot.

There was a difference in soil factors between the sites, and also a great variation within each site. The principal component analysis indicated that soil pH and penetrometer resistance affected germination and plant height. The most prominent result of the multiple regression was the negative correlation of penetrometer resistance and plant height at the second visit. The results show that pH and soil compaction in the topsoil affects the plant performance of climbing beans in this area, although the management, especially staking, also plays a crucial role in the plant performance.

Keywords: Penetrometer resistance, soil pH, staking, CN ratio, Kisii, KALRO

Sammanfattning

Sydvästra Kenya är den mest tätbefolkade delen av Kenya. Denna del av Kenya har relativt bördiga jordar och ett gynnsamt klimat för växtproduktion och är därför ett betydelsefullt område för livsmedelsproduktion. Den höga befolkningstätheten leder till brist på mark och därmed små arealer per gård. Den genomsnittliga gården brukar 0,8-1,8 ha. Störbönor (*Phaseolus vulgaris* L.) har en hög skördepotential på grund av deras indeterminata växtsätt och deras förmåga att klättra, förutsatt att de får mekanisk stöttning. Det är med anledning av detta som projektet Legume CHOICE valde att introducera störbönor i detta område.

Syftet med studien var att avgöra om vissa markfaktorer i området begränsar tillväxten av störbönor. Markfaktorerna som undersöktes var pH, penetrometermotstånd, C- och N-koncentration samt CN-kvoten. Tillväxten mättes genom uppkomst, planthöjd och utvecklingsstadium vid tre tillfällen. Hypotesen var att ett högt pH, hög C- och N-koncentration samt hög CN-kvot skulle innebära en positiv effekt på tillväxten och att ett högt penetrometermotstånd, vilket indikerar eventuell markpackning, skulle ha en negativ effekt på tillväxten.

Data samlades in från fältförsök på 30 gårdar på tre platser i länen Kisii och Migori. Jordprover för pH togs med en jordborr i varje ruta och analyserades på ICRAF:s lab i Nairobi. Jordprover för C och N analys togs enligt LDSF metoden och analyserades vid University of Hohenheim, Tyskland. Jordprover tog för matjorden (0-0,2 m) och för alven (0,2-0,5 m). Penetrometermotståndet mättes på fem platser i varje ruta.

Markfaktorerna skiljde sig mellan platserna och det var även en stor variation platserna emellan. Principalkomponentanalysen indikerade att jordens pH och penetrometermotstånd påverkade uppkomsten och planthöjden vid det andra tillfället. Resultaten visar att pH och markpackning i matjorden påverkar tillväxten av störbönor i området men att även skötseln, speciellt stöttningen, är av stor vikt för tillväxten.

Table of contents

Abbreviations

C – Carbon
CIAT – International Centre for Tropical Agriculture (Centro Internacional de Agricultura Tropical)
GDP – Gross Domestic Product
ICRAF – World Agroforestry Centre (earlier International Centre for Research in Agroforestry)
KARLO – Kenya Agriculture and Livestock Research Organisation
LDSF – the Land Degradation Surveillance Framework
Legume CHOICE – Legume Conception of Household Innovations for Creating legume Expansion
MPa – Mega Pascal
N – Nitrogen
Psi – Pounds per Square Inch

1 Introduction

Kenya has a population of almost 47 million people (FAO-STAT, 2015) and a land area of 580 367 km^2 (CIA, 2015). With a population growth rate of 2 % per year (CIA, 2015) and arable land being only 10 % of the total land area, there is a scarcity of productive land. A large part of the population is involved in agriculture, the industry employing 75 % of the labor force. Along with maize, beans (*Phaseolus vulgaris* L.) are a major crop in Kenya (FAO-STAT, 2015). Beans are a staple food and a primary source of protein in many households in Kenya (Shellie-Dessert & Bliss, 1991). Legumes are plants that can fix nitrogen from the air through symbiosis with Rhizobium bacteria (Reece et al., 2011). Most African farming systems contain legumes and they play a crucial role in soil fertility by raising the nitrogen concentration in the soil if plant residues are returned to the soil, as well as providing quality proteins to humans and animals. Legumes can be divided into various types and beans (a grain legume) being one. Legume CHOICE is a project aiming at increasing the use of multi-purpose legumes among smallholder farmers and is implemented in Kisii county and Migori county in south west Kenya. Climbing bean is a type of Phaseolus vulgaris L. which has an indeterminate growth habit and the ability to climb, if staked, and therefore has a higher yield per area than common beans (Voysest and Dessert, 1991). It is one of the crops being introduced by Legume CHOICE as an effort to address land scarcity. As a newly introduced crop, there is a need to study how climbing beans are affected by soil as well as environmental factors.

Objectives

The objective of the study was to study if differences in site and soil factors explains germination and plant performance of climbing beans (*Phaseolus vulgaris* L.). This was studied in on-farm trials on smallholder farms. Hypothesizes tested was: High penetrometer resistance of a soil indicates soil compaction, which will lead to lower germination rate and poor plant performance. Low pH will lead to low germination rate and poor plant performance. Higher carbon and nitrogen content will lead to higher germination and better plant performance. Lower carbon/nitrogen ratio will lead to higher germination and better plant performance. These factors will have a higher influence than elevation and random variables of the farms.

2 Background

2.1 Agriculture in Kenya

Agriculture is an important industry in Kenya, contributing to 29 % of the country´s GDP and employing 75 % of the labor force (CIA, 2015). The major crops grown in Kenya are maize, tea, coffee, sugarcane, vegetables and fruits. The main exported agricultural products are tea, horticultural products and coffee. The area used for agriculture is 48 % of the total land area (FAO-STAT, 2015)

Although agriculture plays a major role in Kenya's economy it is not technically advanced. Most of the farmers in Kenya are smallholder farmers, with the average farm size in Kenya being 2.5 ha. This is larger than the average in Africa but much smaller than the average farm in North America, Latin America and Europe (Salami & Brixiova). According to High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE) (2013), smallholder farms are run by families using mainly family labour. The resources are scarce, especially land, and subsistence cropping is common.

The Highlands of Kisii is a part of Kenya that receive some of the highest precipitation in the country. The annual rainfall is between 1200 mm and 2100 mm, distributed in a bimodal pattern. The long rains occur from late February to May, with a growing period of 200 days. The short rains occur from September to November, giving a growing period of 100-150 days. The mean average temperature is 18°C, with the mean maximum temperature being 27°C, and the mean minimum temperature being 11°C (Jaetzold & Schmidt, 1982).

The soils in the area of Kisii have a moderate to high fertility, with some areas that have low fertility (Jaetzold & Schmidt, 1982). The main soil types are Eutric Cambisols, Nitosols, Luvisols and Phaeozems. Eutric Cambisol is a weakly developed soil that has not evolved any distinct horizons (Jones et al., 2013). Eutric Cambisol is common in many parts in Africa but the characteristics vary depending on the parent material. The soil contains weatherable minerals, which makes it rich in nutrients and it can sustain demanding crops if water is available (FAO-UNESCO 1977). Nitisols have a high iron content, which gives them their red color (Jones et al., 2013). The amount of weatherable minerals is high compared to many other tropical soils. Therefore, the cation exchange capacity is relatively high (Driessen et.al, 2001). They are considered as one of the most productive soils in the humid tropics. Phosphorus fixation is significant, but acute phosphorus deficiency is rare. The soil is deep, well-drained and has a fair water holding capacity. Phaeozems are soils common in a steppe-climate or in elevated land in the tropics (Driessen et.al, 2001). Phaeozems are rich in organic matter in the topsoil, which gives them a dark-colored upper layer. They are porous soils with a strong and stable structure. The fertility is high in these soils since the organic matter makes them rich in nutrients (Jones et al., 2013). Luvisols have a high clay content, especially in the subsoil, since the clay moves downwards. The clay and the presence of weatherable minerals makes it fertile, thanks to its nutrient-holding capacity. They also have a well-developed soil structure and a good water-holding capacity (Jones et al., 2013, Driessen et.al, 2001).

Kisii Central District has a rural population density of 844 persons/km^2, which qualifies it as one of the most densely populated parts of Kenya (Kenya National Bureau of Statistics, 2010). The district of Rongo has a rural population density of 312 persons/km2. This should be compared with the average population density of Kenya, which is 66 persons/km2. The high population density is reflected in farm size. The average farm size, among the farms participating in the Legume CHOICE programme in Kisii County, was 0.8-0.9 ha (Oborn et al., 2015). Rongo is not as densely populated and the average farm size of participating farms was 1.8 ha.

Maize and beans are produced on half of the area designated for annual crops in the Kisii district (Jaetzold & Schmidt, 1982). The average yield of dry beans in Kenya is 500 kg per hectare (FAOSTAT, 2013). The average yield of beans in Kisii District in the first rains is 1000 kg per hectare as a sole crop and 521 kg per hectare when intercropped with maize (Jaetzold & Schmidt, 1982). The yields are generally lower in the second rains. A small part of the bean crop is sold at the local market but the main part is consumed in the home (Jaetzold & Schmidt, 1982). Beans are a major staple crop and a primary source of protein. The estimated consumption per capita is 21 kg per person and year in Kenya (Shellie-Dessert & Bliss, 1991).

2.2 Legumes

Legumes are plants that can live in symbiosis with *Rhizobium* bacteria, which has the ability to fix nitrogen from the air (Reece et al., 2011). The bacteria are attached to the roots of the plant and receive carbohydrates from the plant. In exchange the plant receives nitrogen compounds from the bacteria. This is a very useful collaboration, which gives the plants an advantage when grown in poor soils. The exchange of carbohydrates for nitrogen compounds is costly for the plant and if there is nitrogen available in the soil the plant will utilize that rather than from symbiosis. The nitrogen is stored both in the above and below ground plant biomass. If the plant residues are left in the field, the fixed nitrogen will be released in the soil when the plant decomposes and contribute to the amount of nitrogen available for the next crop.

Legumes can be divided into various types depending on their phenology, growth-period duration or use. The different types are annual grain legumes, perennial grain legumes, annual fodder legumes, perennial fodder legumes, tree fodder legumes and green manure tree legumes. Because of the heterogeneity of Kenyan farms, there are different specific niches for specific types of legumes in time and space that can suit different farms.

Legumes are high in good quality proteins which make them excellent as food for humans and fodder for animals. Legumes are also a basic ingredient in food traditionally eaten in Kenya. Through their nitrogen-fixing capacity and quality products, legumes have a great potential to contribute to rural livelihoods and natural resource status, either in form of grains for home consumption or sale, fodder for livestock, green manure or fuel wood. Most African farming systems today contain legumes but the area is often limited in space or time.

2.3 Legume CHOICE

Legume CHOICE is a 3- year project in Kenya, Ethiopia and Democratic Republic of Congo jointly organized by International Institute of Tropical Agriculture (IITA), International Livestock Research Institute (ILRI), International Centre for Research in Agroforestry (ICRAF), University of Hohenheim (UoH), Universite Catholique de Bukavu (UCB) and Kenya Agricultural and Livestock Research Organization (KALRO). The aim of the project is “to improve food and nutrition security, reduce poverty, and enhance the production environment of smallholder farmers and rural populations, in particular women, through facilitation of the smart integration and use of multi-purpose legumes, providing food, protein, feed, fuel, and/or organic matter in crop-livestock systems” (Legume CHOICE, 2015) In Kenya the project is implemented by ICRAF and KALRO Kisii. The project is based in Kisii County and Migori County in south west Kenya. The project started in May 2014.

Four sites were chosen, with the aspect of geographical location and market access in mind. These sites were Kitutu Chache North (good market access) and Nyaribari Chache (medium market access) in Kisii county, and Rongo (good market access) and Suna West (poor market access) in Migori County. To identify farmers suitable for the project, a baseline survey and a farm characterization was done. The baseline survey consisted of a transect walk at each site during which farmers were interviewed briefly. The baseline survey included 307 farmers in total across the four sites. The farm characterization included 96 farmers that each where interviewed for approximately two hours. The baseline survey and the farm characterization aimed at acquiring knowledge about age and education of household head, household size, farm size, land tenure, cropping systems, legumes currently grown and production data, such as yield. To gather further information about legumes already present on the farms and constraints for legume production, a Focus Group Discussion was held at each site in August 2014. Men and women discussed in separate groups. The topic for the Focus Group Discussion was constraints for legume intensification (World Agroforestry Centre, 2014).

For the long rains season of 2015 it was decided by the Kenyan team, after evaluation of the Farm Characterization and Focus Group Discussion, that climbing beans might be a suitable implementation in Kitutu Chache North, Nyaribari and Rongo, whereas common beans were prioritized in Suna West (Personal communication Ingrid Öborn).

2.4 Phaseolus vulgaris – Climbing beans

Phaseolus vulgaris L. originates in America and was domesticated 7000 to 8000 years ago (Gepts & Debouck, 1991). Since then numerous varieties has evolved and spread throughout the world. It is a primary source of protein in most of Latin America and Eastern Africa (Shellie-Dessert & Bliss, 1991). It is usually referred to as common bean or bush bean (Voysest & Dessert, 1991).

Common beans are classified by CIAT into four groups, depending on their growth habit. Class I has a determinate growth habit. Class II-IV have an indeterminate growth habit. Out of these class IIIb and class IV are referred to as climbing beans or pole beans (table 1). The indeterminate growth allows them to produce a greater number of flowering sites per plant and thus more pods per plant (Graham & Ranalli, 1997). This suggests that they would be suitable for areas where arable land is scarce, as they can produce a high yield on a small area compared to common beans with a determinate growth habit.

Table 1. *Classification of beans based on Voysest and Dessert (1991).*

Growth habit	Classification by CIAT		Everyday name
Determinate	Class I		Bush or common bean
Indeterminate	Class II	Class IIa	
		Class IIb	
	Class III	Class IIIa	
		Class IIIb	Climbing or pole
	Class IV	Class IVa	
		Class IVb	

Africa is the world's second biggest producer of dry beans, producing approximately 10 % or 1.4 million t/year (Shellie-Dessert & Bliss, 1991). Central and East Africa is the major area for bean production in Africa, and Kenya contributes with 9 % of the total production in Africa.

Climbing beans and bush-type beans have a similar yield potential under optimal circumstances, climbing beans yielding 6000 kg/ha (Singh, 1991a) and common beans 5000 kg/ha (Graham and Ranalli, 1997). However, climbing beans have proven to have a higher on-farm yield potential. The expected yield from Kenya Seed Company is 1350-2250 kg/ha for common beans and 3375-4500 kg/ha for climbing beans. In on-farm trials in the central highlands in Kenya yields of 1300 kg/ha of climbing beans have been recorded (Raemakers et al., 2012). When discussing yields attention must be payed to if the crop was grown as a sole crop or intercropped as this highly affects the yield potential. Sole crops are generally higher yielding, but intercropping is often favoured by smallholder farmers because this system gives more stable yields with less inputs (Francis & Sanders, 1977).

Climbing beans are most commonly grown during the long rain season, as they have a longer growth cycle than common beans (Woolley et al., 1991). In Rwanda, climbing beans have a period of 5-5.5 months from planting to harvesting at 1750-2000 meters above sea level, whereas 6-6.5 months are required at 2000-2400 meters above sea level (Woolley et al., 1991, pp 688). A decreasing temperature with higher altitudes thus leads to a longer growth cycle. Farmers in the Great Lakes Region in Africa prefer early maturing varieties of beans, even though they yield less. The extra time in the field for later maturing varieties is considered as a great risk. This is of less importance in areas where the rainfall is higher and more reliable (Voss & Graf, 1991).

Climbing beans are grown in areas of the Great Lakes region in Africa that are high in rainfall, have high population density and have fertile soils. The motivation for growing climbing beans in this region appears to be greater resistance to soil-borne diseases, due to their climbing ability, and the need to intensify production per land area due to the high population density. The cropping systems vary within the region. Sole crops of staked climbing beans are more common on altitudes of 2000-2300 meters above sea level, whereas intercropping with maize or bananas is more common on lower altitudes (Woolley et al., 1991).

Staking of the climbing beans is necessary for good plant performance and high yield. For example, Francis, Prager and Sanders (1977) compared trellises and intercropped maize (simultaneous planting) with no support system. The result showed that the absence of a support system leads to a significantly lower yield and number of pods per plant. A good support system prevents lodging and allows the beans to spend less resources on mechanical support structures in tissues (White & Izquierdo, 1991). A variety of support systems can be used. The most common are dead wood stakes, trellising or live staking by intercropping, most commonly with maize. However, climbing beans yield less when intercropped with maize than when cropped as a sole crop, most probably because of the competition for resources such as light, water and nutrients (Francis, Prager & Sanders, 1977, Niringiye, 2005). The height of climbing beans depends on the staking material. Davis and Garcia (1983) used staking material with the height of 1.8 m and found that the beans cannot climb higher than the staking material, and if that is insufficient the beans cannot reach their potential height.

Figure 1. Climbing beans looking for support when not staked in time.

2.5 Soil related constraints to bean production

As with other crops, there are several agronomic factors that are important for a successful bean production. These are land preparation, fertilization, crop protection, weed control and water supply (Thung, 1991). Smallholder farmers with poor resources and low technology are limited in their choices of management practices regarding these factors. The most common constraints to bean production is low soil fertility, water stress and diseases (Fageria, 2002). Beans are sensitive to water stress, especially during the flowering period (Thung, 1991). They are also sensitive to excess water and are ideally planted on well-drained soils. Compacted soils affect bean yields negatively (Buttery, Tan & Park, 1993), especially under dry conditions (Buttery, Tan, Drury, Park, Armstrong & Park, 1998). The amount of water available to the bean plant is affected by the extent of the root system. The root development is influenced by the penetration resistance of the soil. Root penetration is increasingly restricted from 0.5 MPa penetrometer resistance and is totally restricted when the resistance reaches 2.5 MPa (Groenevelt et al., 2001). The optimum soil pH for bean is between 6.0 and 7.5 (Thung, 1991, pp 792) and they are classified as nonacid-tolerant plants. If the soil is too acid it can lead to such high levels of Al^{3+} that it becomes toxic for the plants and negatively affect the plant roots (Eriksson et.al, 2011, Thung, 1991, pp 781). The availability of mineral nutrients for the plant and the efficiency of fertilizer application can differ with variations in pH. The average carbon content in soils in eastern Kenya is 0.8 % and in central Kenya 2 % (Zschernitz, 1973, in Thung, 1991). The amount of organic matter in the soil influences soil structure, water-holding capacity, nutrient availability, cation exchange capacity and can have a mitigating effect on Al3+ toxicity (Eriksson et al., 2011).

The soil conditions does not only affect bean plant performance, but also the Rhizobium bacteria's performance (Smartt, 1990). For example, Amijee and Giller (1998) found that the plant vigour of common beans was poor in soil with low extractable soil P. This was thought to be because the root nodulation of Rhizobium was less frequent in these soils, resulting in lower nitrogen fixation. Low pH is also known to affect root nodulation negatively through deficiency of other nutrients and Al^{3+} toxicity (Giller, 2001).

3 Material and Methods

3.1 Study sites

Climbing beans were planted at three sites. Kitutu Chache North and Nyaribari Chache in Kisii County and Rongo in Migori County. Kitutu has the biggest variation in elevation, ranging from 1630 meters to 1826 meters above sea level. Nyaribari is the most elevated site, ranging from 1767 meters to 1894 meters above sea level. Rongo is flatter and less elevated with elevations ranging between 1467 meters and 1527 meters above sea level.

The average farm size among the participating farms were 2 acres in Kitutu Chache North and 2.25 acres in Nyaribari Chache. Rongo is not as densely populated therefore the average farm size was 4.5 acres. The average household size (number of individuals eating and living under the same roof) is 5-6 persons in all sites. The households have been classified into typologies depending on the farm size, the amount of fertilizer used and the amount of livestock on the farm. There are three typologies: wealthy, medium and low. The participating farms have been chosen so that the three typologies are equally represented. The typology of a household can for example give a hint of the household's possibility to hire casual labor.

Common beans are the most commonly grown legume on the farms and they are usually intercropped with maize. The yields of grain legumes are between 100-200 kg per hectare and season in all sites (Baseline Survey). There is a wide range of constraints to legume production, both biological and socio-economical. These are the biological constraints that were mentioned by the farmers during the Focus Group Discussion: pests and diseases, low soil fertility, inadequate farm inputs, low seed quality, weather variability and poor farming methods and crop management. The socio-economic constraints mentioned were: poor markets, small land sizes, inadequate capital and inadequate labor.

3.2 Plant material

The climbing beans planted were of the varieties Kenya Mavuno (MAC64), Kenya Safi (MAC13) and Kenya Tamu (MAC34). They are commercially sold by Kenya Seed Company. They are of the type medium altitude climbers (MAC). The duration to maturation ranges between 90-130 days (Table 2). The expected yield, according to Kenya Seed Company, is 3375-4500 kg/ha. The seed was treated with a seed dressing called Marshal Murtano (personal communication Dr, Kwach, KALRO, Kenya).

Table 2. *Characteristics of Bean varieties from Kenya Seed Company.*

Bean variety	Duration to Maturation	Grain Colour
Kenya Mavuno (MAC64)	90-120 days	Dark red mottled
Kenya Safi (MAC13)	110-130 days	Red mottled red with white specks)
Kenya Tamu (MAC34)	100-125 days	Speckled sugar (white with red to brown specks)

3.3 Plot design and management

Legume CHOICE aim at a bottoms-up approach and involving the farmers as much as possible. Therefore, the trials were designed on-farm and most of the management was done by the farmers. This has the advantage that the results are not biased by different managements or inputs applied by researchers, and are therefore more realistic to what the actual plant performance and yield would be as a farm crop. The disadvantage is that it is more difficult to control the management, which leads to a heterogeneous management in time and technique.

24 farms in each site took part in the intervention. Eight farms were selected out of these and were planted by field technicians from KALRO. The other 16 farmers were given seed and fertilizer and instructions on how to plant. All management after planting was done by the farmers, KALRO only gave advice on when and how to stake. Samples were taken from ten farms in each site. The majority of the farms were planted by KALRO, and the rest of the farms were chosen from the farmers that had followed the instructions most closely. There was only one bean variety at each farm. The aim was to distribute the bean varieties evenly between the three sites and the different categories of farmers. This did not succeed completely, which makes the plot design rather unbalanced.

Figure 2. Planting done by KALRO with farmer over-looking.

Planting was done between the 31st of March and the 14th of April. Two plots were established at each farm. One of the plots were later planted with the legume tree *Gliricidia Sepium*, which the following season will provide live staking for the climbing beans. A plot measured 6x6 meters and the two plots were one meter apart. In each plot 8 rows were established, in which beans were planted in holes 0.3 m apart (inter row spacing 0.75 m). Two seeds were planted together at 0.05 m depth in each hole. Five grams of diammoniumphosphate fertilizer (DAP) was applied to each hole which is equivalent to 220 kg/ha. There was a great variation in how closely the farmers that carried out the planting themselves had followed the instructions. The field technicians from KALRO visited the farms 3-4 weeks after the emergence of the beans and explained to the farmers how to stake the beans. There was also discussions between the farmers and the extension workers about weeding, plant emergence and plant performance.

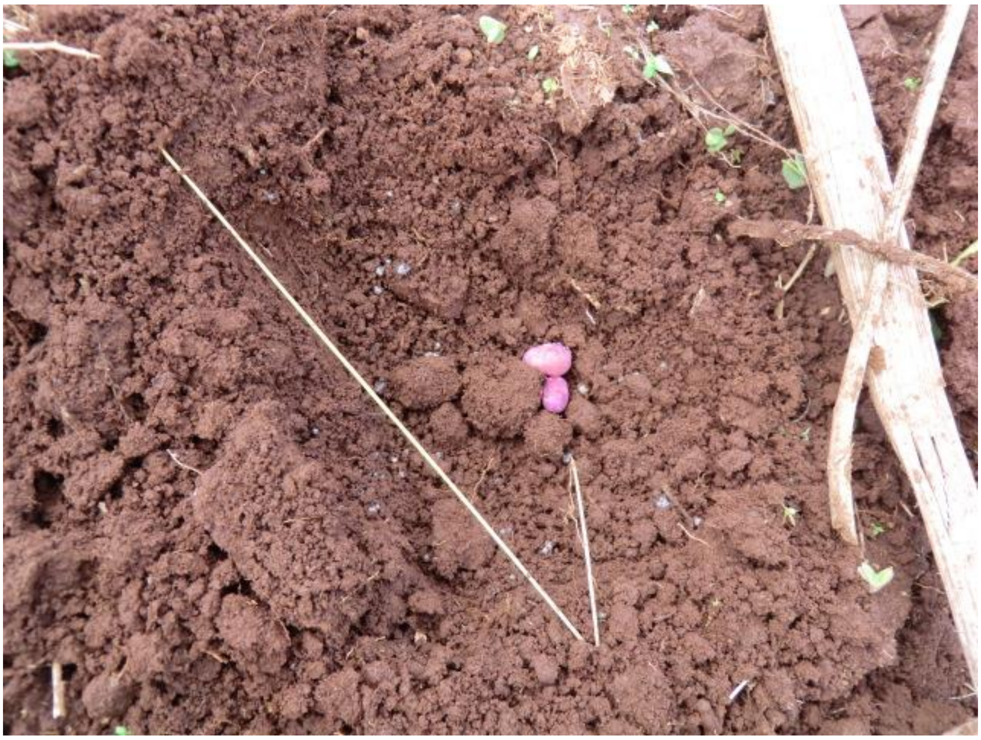

Figure 3. The beans were planted two in each hole, together with Diammoniumphophate fertilizer.

3.4 In situ

3.4.1 Recording of plant performance

The observations and measurements on the farms could not be done at the same time in all sites due to the different geographical locations and other practical circumstances, such as access to transport to the sites. A germination count was done 14-21 days after planting. The germination rate was recorded by counting the emerged plants in three rows and then calculating an average, which was then divided by the amount of seeds planted in a row to receive the germination percentage. Plant performance was measured by growth stage (Schwartz & Langham) and height. The plant performance was recorded three times, 14-21 days, 22-34 days and 42-53 days after planting respectively. The general impression of the plot was also noted.

Figure 4. Measuring the plant height.

3.4.2 Soil sampling and penetrometer

Soil samples for pH-measurement and water content were taken between the 30th of April and the 22nd of May. Samples were taken from ten farms in each site. Soil sampling was done from one location in the middle of each plot, using a soil auger. One sample was taken for the topsoil (0-0.2 m) and one for the subsoil (0.2-0.5 m).

The samples were put into plastic bags to preserve the moisture content until the water content analysis was done.

Soil sampling for carbon and nitrogen content was taken by a field technician from ICRAF, as these results are to be used for various studies within the Legume CHOICE project. The sampling was done during April and May 2015, and the method used was the LDSF sampling design (Vågen et al., 2013). The sampling was done for topsoil (0-0.2 m) and subsoil (0.2-0.5 m).

Figure 5. Soil sampling by ICRAF.

Penetrometer measurements were done with a DICKIE-john soil compaction tester, using a ½ inch tip. Measurements were done with five replications in each plot, one in each corner and one in the middle of the plot. The resistance was recorded in pounds per square inch (psi) for every 10 cm down to 50 cm. The scale suggested by the manufacturer for the penetrometer reading, was green 0-200 psi, yellow 200-300 psi and red >300 psi. The colors represents how well the roots can grow in the particular range, with green meaning that the roots grow well, yellow means growth is fair and red means they grow poorly. For this data collection modifications were done to this scale to make it more exact, and to come up with fixed numbers that were possible to use in statistical analyses (Table 3).

Table 3. *Relationship between penetrometer readings and pressures required for penetration of soil (range per colored field and fixed values used for statistical analysis).*

Scale	Range (psi)	Fixed number (psi)	Fixed number (MPa)
Green 1*	0-100	50	0.345
Green 2**	100-200	150	1.034
Yellow 1*	200-250	225	1.551
Yellow 2**	250-300	275	1.896
Red 1*	300-400	350	2.413
Red 2*	400-500	450	3.103
STOP (not able to penetrate further)	>500	550	3.792

*Lower half of colour scale

** Upper half of the colour scale

3.4.3 Soil analysis

Water content was analyzed by weighing 40 g of wet soil from the field. The analysis took place in the lab at KALRO Kisii 1-3 days after the sampling was done, due to practical circumstances such as the laboratory being closed during weekends. The soil was dried by air for 2-5 days and then weighed again. A digital scale was used with an accuracy of 0.01 g.

The dry soil was prepared for pH measurement by sieving it, using a 1.00 mm sieve of steel. The pH was measured at the ICRAF laboratory in Nairobi, using distilled water according to the method by van Reeuwijk (2002).

The soil was analyzed for carbon and nitrogen content by dry combustion, using a Perkin Elmer elemental analyzer. This was done in Germany, at University of Hohenheim.

3.5 Dialogue with farmers

Each farm was visited three times for recording of plant performance. During these visits there was a dialogue with the farmer, if he or she was present. Some farmers did not speak English. In these cases the communication went by the field technicians from KALRO that spoke Swahili or the local language in Kisii. These dialogues contained information about the farmer's perception of the performance of the beans, local weather conditions, management systems of the farm and the farmer's thoughts on staking of the beans. The gathering of this information was in no way consequent and no specific method was used. They were first and foremost a way for the author to understand the context in which the research took place.

3.6 Statistical analysis

The plant height was adjusted to the number of days since planting so that this would not interfere with the statistical analyses. To achieve this we calculated the height the plants should have had at the average time of the visits. First an average time of visit was calculated. A regression of all the plant heights against the three visits was done. The correlation received was used to calculate the change in height, from the average time of visit.

Firstly the data was analyzed by analysis of variance, to see if there were any differences between the varieties. No significant differences were found, and the analysis was done without variety as a parameter in the following analyses. Secondly, the data was analyzed statistically by Analysis of variance (JMP) to see if there was a difference between the sites in penetrometer readings, pH, water content, N-content, C- content and C/N-ratio. This was also done for adjusted plant height and germination. Growth stage was excluded from the Analysis of variance, as this could not be adjusted to the time of planting.

A principal Component Analysis (JMP) was done to see which factors were correlated. Multiple regression (Minitab Inc, 2007) was done for germination rate versus elevation, penetrometer, pH, N-concentration, C-concentration and CN ratio and for plant height and growth stage at the tree times of visit vs elevation, penetrometer, pH, N-concentration, C-concentration and CN ratio. For the regressions of germination rate and the first plant height and growth stage only soil data for the topsoil was used, whereas topsoil and subsoil data were used for data from the subsequent visits. It must be noted that the experiment was not balanced, and strongly affected of the different management practices applied by the farmers, which makes the statistical analysis somewhat unreliable.

4 Results

4.1 Dialogue with farmers

Most farmers had not heard of climbing beans before. Some were interested of how they would perform and had high hopes that they would yield well. Others had a more casual attitude towards the trials and some showed very little interest. The difference in attitude also had to do with how involved the farmers were in farming. For some it was there only source of income, others were barely at the farm as they were engaged in work elsewhere. Some farmers were observant on when the beans needed staking and had already started before the team from KALRO came to demonstrate on how to do it. Others had observed the need but were unsure of how to do it, or hoped that KALRO would provide them with the staking material. There were also farmers that did not stake in time, this could be because of lack of staking material or lack of time.

Figure 6. Staking done well and in time.

4.2 Plant data

The germination rate varied from 14 % to 88 % for individual farms. Kitutu had the highest average germination, Rongo second highest and Nyaribari lowest (table 4), but differences were not significant. There was no significant difference in plant height between the sites at the first and third visit, although the variation in plant height was between 0.005-0.1 m at the first visit and 0.56-1.6 m at the third visit. However, the average plant height at the time of the second visit was significantly different between the sites. Rongo and Kitutu were equal but Nyaribari was lower (table 4).

4.3 Soil data

The penetrometer results for the topsoil was significantly different between the sites (table 4) with Rongo standing out as the topsoil with the highest penetration resistance. The penetrometer result for the subsoil was not significantly different between the sites. The pH ranges between 4.4 and 6.2. There was significant differences between the sites for topsoil but not for the subsoil (table 4). Kitutu has a higher pH than the other sites in the topsoil. There are significant differences between the sites for C-concentration, N- concentration, CN ratio and water-content. Rongo is the site that stands out among the three sites, having a lower C-concentration, N-concentration and water content but a higher CN ratio.

4.4 Principal component analysis

The Principal component analysis shows that the sites differ from each other by distinguishing themselves into three separate groups, although Kitutu and Nyaribari share some traits (Figure 7). The differences are caused by the elevation, carbon and nitrogen content in the soil and the carbon/nitrogen ratio. The principal component analysis also shows that the planting dates differ between the sites and that the planting date and elevation are closely linked.

Within each site there was a great variation. According to the analysis the most important variables behind the variation was the pH of the soil and the penetrometer resistance, especially in the subsoil, as well as the germination rate and the plant height. The fact that the germination and the plant height of the beans co-varied with the soil pH and the penetrometer resistance indicates that they were the most important variables impacting germination and growth.

The principal component analysis indicates that the growth stage was primarily determined by the number of days since planting, penetrometer resistance (especially in the topsoil) and the N concentration and that pH was of less importance.

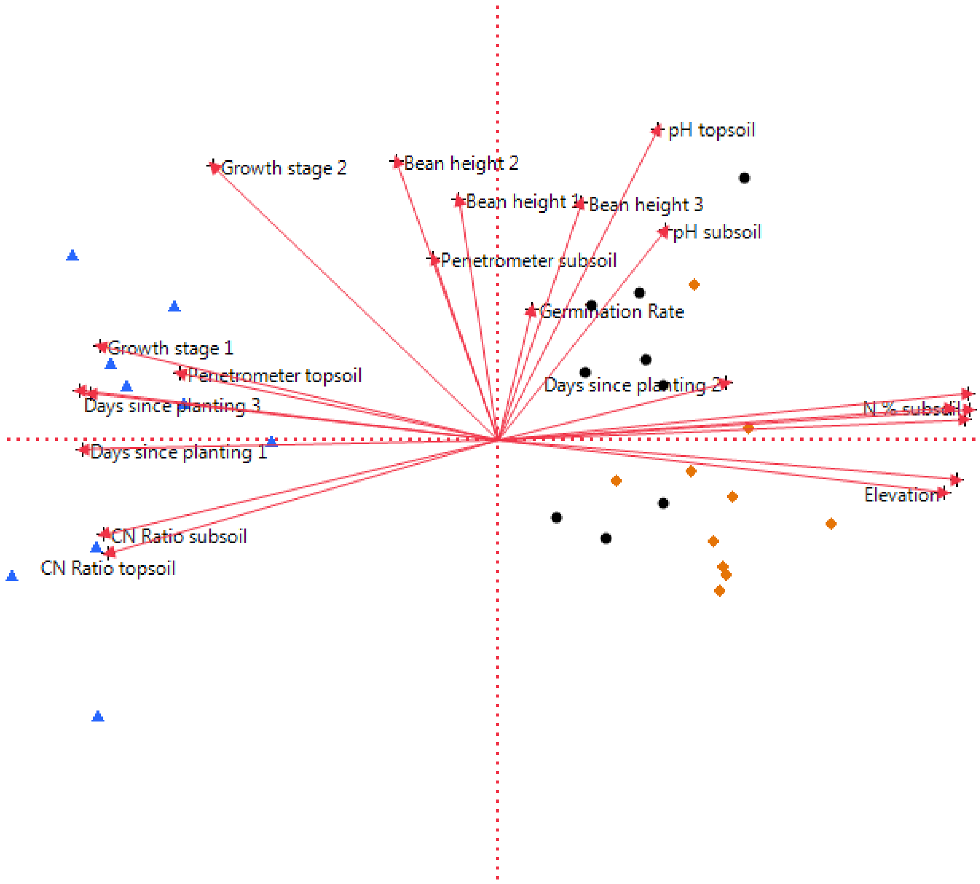

Figure 7. Principal component analysis over soil factors and plant parameters. Component 1 (vertical) 52 % and component 2 (horizontal) 12.6 %.

Table 4. *Results from Analysis of variance. Data presented as LSMeans. Plant variables are across bean varieties, soil data are for topsoil (0-0.2 m) and subsoil (0.2-0.5 m), respectively. Values followed by the same letter are not significantly different.*

Site	Germination %	Height 1 (m)	Height 2 (m)	Height 3 (m)	pH		Penetrometer (MPa)		C %		N %		CN ratio		Water content %	
					Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Kitutu	50	0.08	0.57 a	1.30	5.4 a	5.3	0.717 b	1.73	2.248 a	1.692 a	0.211 a	0.167 a	10.7 b	10.2 b	22 a	22 a
Nyari-bari	39	0.08	0.40 b	1.39	5.1 b	5.2	0.655 b	1.65	2.400 a	1.939 a	0.225 a	0.182 a	10.6 b	10.6 b	20 a	20 a
Rongo	45	0.08	0.56 a	1.28	5.0 b	5.0	1.04 a	1.74	1.060 b	0.811 b	0.789 b	0.0578b	14.5 a	15.3 a	15 b	16 b
p-value	ns	ns	0.0054	ns	0.0107	ns	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001

4.5 Multiple regression

The Multiple regression shows a slightly different view of the relating soil factors and plant performance than the Principal component analysis (table 5). The penetrometer resistance in the topsoil was significantly correlated with the development of the beans at several occasions but the significance was not always convincing and changed depending on the statistical model (germination), or was strongly influenced by a few values (growth Stage 1). Most reliable was the negative correlation between penetrometer resistance in the topsoil and the plant height at the second visit.

The C- and N-concentration was identified as significantly correlated with several plant performance parameters, although the fact that the coefficients alternated between negative and positive as well as C- and N-concentration being closely correlated makes the results less reliable.

Table 5. *Correlation coefficients and p-value for multiple regression of plant performance parameters versus soil factors. Soil data are for topsoil (0-0.2 m) and subsoil (0.2-0.5 m), respectively. Subsoil data was excluded for plant parameters at first visit.*

Factors	Germination		Height 1		Height 2		Height 3		Growth Stage 1		Growth Stage 2	Growth Stage 3	
	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff		p-value	Coeff
Elevation	ns		ns		ns		ns		ns		ns	ns	
Penetrometer topsoil	0.048	0.01939	ns		0.006	-0.476	ns		0.000	0.00824	ns	0.041	0.429
pH topsoil	ns		ns		0.013	39.1	ns		ns		ns	ns	
N % topsoil	0.020	-7.68	0.049	-39.3	ns		ns		0.001	-22.69	ns	0.039	-1309
C % topsoil	0.002	1.120	ns		ns		ns		0.007	1.847	ns	ns	
CN ratio topsoil	ns		ns		ns		ns		0.002	-0.1499	ns	0.000	-17.93
Penetrometer subsoil	n/a		n/a		ns		ns		n/a		ns	ns	
pH subsoil	n/a		n/a		ns		ns		n/a		ns	ns	
N % subsoil	n/a		n/a		ns		ns		n/a		ns	ns	
C % subsoil	n/a		n/a		0.034	91.1	ns		n/a		ns	ns	
CN ratio subsoil	n/a		n/a		0.047	-5.95	ns		n/a		ns	0.003	13.50

5 Discussion

The staking of the plants varied a lot. Some farmers did an excellent job using tall and sturdy stakes and putting them up soon after the visit from KALRO. Unfortunately, not all farmers did the staking as well as that. Many farmers used insufficient stakes that were too short and too weak. Others did not stake the whole plot or did the staking very late. This affected the plant heights a lot, as is also mentioned in the literature (Francis, Prager and Sanders, 1977). To avoid this as a source of error the plants that were most properly staked were chosen when possible. Other management practices such as weeding and erosion control measures also differed a lot between farms. The principal component analysis showed that the planting dates differed between the sites which is explained by the fact that the planting and distribution of seeds was done under separate weeks by the KALRO team. This also explains why the planting date and elevation are closely linked, since the sites are on different elevations.

5.1 Plant data

The great variation in germination rate is difficult to find an explanation for. None of the variables in the multiple regression are significant. Perhaps the answer is in variables not noted or measured in this experiment, such as soil-borne diseases, pests, soil erosion or birds eating the seeds.

It is only at the second visit that there is a significant difference in plant height between the sites. This might be explained by the fact that at the first visit the plants had not had time to develop differently and at the time of the third visit the plants had been affected by the very different management practices, including staking, which might have hidden the potential height differences. It is notable that Nyaribari is the site with the lowest plant height at the second visit. Nyaribari is the site with the highest elevation and climbing beans are supposed to do well at high elevations, according to the literature. However this difference is not significant at the third occasion, so it might not be significant in the long term.

Rongo had the highest penetrometer resistance in the topsoil, indicating some compaction of this layer. This was notable when the measurements were done. However, Rongo was the site were the measurements were done last and therefore it had been a longer while since cultivation in preparation for sowing and also since weeding, which might affect the results. Further, Rongo had a significantly lower water content compared to the other sites and this can affect the penetrometer resistance (Vaz et al., 2011). A statistical analysis of the data showed that there was a correlation between the penetrometer resistance and soil water content, although the outcome of the multiple regression did not differ with penetrometer resistance adjusted to the water content and was therefore not included. This might be because the penetrometer resistance is also influenced by the texture of the soil, which was not known in this, case or that it was indeed compacted

The Principal component analysis indicated a correlation between growth stage and number of days since planting at the first and third visit. The growth stage of the beans at the first and second visit were vegetative. The growth stage scale was under the vegetative phase based on how many leaflets the plant had and it might not be so surprising that this potential correlation weakened as the time since planting increased. That the correlation strengthened when the beans went into the generative phase fits well with that the three varieties have approximately the same length of growth cycle from planting to harvest, and therefore also to flowering (Singh,1991b).

5.2 Correlation of plant performance and soil factors

The hypothesis that the lower penetrometer resistance the better the plant performance is proved for the plant height at the second visit. But it is contradicted for germination and growth stage at the second and third visit. A possible explanation for this could be that the penetrometer resistance is not high enough to have a negative impact on root growth and the plants not being drought stressed due to sufficient rainfall. Groenevelt et al. (2001) sets the limit for totally restricted root growth at 2.5 MPa and Rongo, the site with the highest penetrometer resistance is well below that figure. Penetrometer resistance is also affected by water content in the soil. A possible explanation could be that the soil was not compacted enough around the seed at the time of planting and therefore did not have sufficient contact with the soil and as a result did not get enough water to germinate.

The hypothesis for the pH was proved for the topsoil. The plant height at the second visit had a positive correlation with pH in the topsoil. The soil pH of the sites are generally fairly low and a higher pH results in a more neutral soil with better root environment and a higher amount of nutrients available to plants (Thung, 1991, Eriksson et al., 2011).

The hypothesis for soil N concentration was not proven. It showed a negative correlation instead of a positive. The hypothesis that a lower CN ratio would lead to a better plant performance was proven for growth stage at the first and second visit. A lower CN ratio generally indicates that there is a net mineralization of nitrogen, which in turn means that there is plenty of nitrogen easily available for the plants. An explanation for the unexpected result could be that a higher N concentration in the soil led to a higher growth of weeds that stole the nitrogen from the beans. As stated before, the management, including weeding, was very heterogeneous between the farms and some farms had a high incidence of weed and other weeded the plots leading to less weeds.

At higher carbon concentration in the soil affects the soil positively regarding structure and nutrient availability. This is expected to lead to a better root environment and a good supply of nutrients for the plant, which ensures better plant performance. The hypothesis that a higher carbon content would lead to better germination and plant performance was partly supported but not to the expected extent and only during germination and early growth. This may be due to the relatively reliable rainfall, stable soil structure and good drainage at these sites, making the organic matter less crucial than under drier conditions and more unstable soils.

Information on the harvest results is missing in this set of data, since the beans have a long growth cycle but the data can be seen as an indication of yield. Farmers are able to influence some soil factors by soil conservation and fertilizing, and the management of the beans, such as staking and weeding, which should raise the yield. The aim Legume CHOICE had with introducing climbing beans in the area was to get a high yield of a small area of land, since land is scarce. The key to achieving this is to stake the beans with the best technique and at the right time. If done properly it will increase yields and decrease the risk of pests and diseases. Other management practices of importance is weeding and erosion control, especially on steep land. Maintaining the pH at the current level, or raising it if possible, is also a crucial step to raising the yield. A crucial factor for a wider adoption of climbing beans is the availability of seeds. In further studies it would be of interest to look into why the germination rates vary and are generally low. In conclusion climbing beans are suitable in this area and have the possibility to become a successful crop if managed well

Acknowledgements

I would like to thank Sigrun Dahlin, Swedish University of Agricultural Sciences for excellent help with support during the planning of the field work and the writing of the thesis. I would also like to express my gratitude to Ingrid Öborn for introducing me to the Legume CHOICE project and ICRAF. Many thanks also to Irene Okeyo at ICRAF Kisumu and to Maurice Shiluli at KALRO Kisii for providing information about the project and for introducing us to KALRO Kisii. Thank you also to the staff at KALRO Kisii for the welcoming atmosphere and providing me with office space, the use of the soil lab and transport to the fields. I am also very thankful to Michael Maranga and Josaia Mugaka, field technicians at KALRO, for introducing me to the farmers and for help with interpretation. Thank you Eric Komsoon, PhD student in Legume CHOICE project, for the advice regarding my field work and lab analysis. Thank you to staff and students at ICRAF Nairobi for showing us around and for letting me do my pH measurements in the lab. Last, but not least, thank you to the farmers in Kitutu, Nyaribari and Rongo for letting us perform our research on your fields and for answering all my questions, thank you for your patience.

References

Amijee F & Giller K.E. 1998. Environmental constraints to nodulation and nitrogen fixation of Phaseolus vulgaris L. in Tanzania. I. A survey of soil fertility, root nodulation and multi-locational responses to Rhizobium inoculation. African Crop Science Journal, Vol 6. No. 2, pp 159-169.

Buttery B.R, Tan C.S, Drury C.F, Park, S.J, Armstrong R.J & Park K, Y. 1998. The effects of soil compaction, soil moisture and soil type on growth and nodulation of soybean and common bean. Canadian Journal of Plant Science, Vol 78. No. 4, pp 571-576.

Buttery B.R, Tan C.S & Park S.J. 1993. The effects of soil compaction on nodulation and growth of common bean (Phaseolus vulgaris L.). Canadian Journal of Plant Science, Vol 74. No 2, pp 287-292.

CIA. 2015. The World Factbook [Online]. Central Intelligence Agency. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html [Accessed 6th of May 2015].

Davis J.H.C & Garcia S. 1983. Competitive ability and growth habit of indeterminate beans and maize for intercropping. Field Crops Research, vol 6, pp 59-75.

Driessen P, Deckers J, Spaargaren O & Nachtergaele F, 2001. World Soil Resources Report (94)- Lecture Notes on the Major Soils of the World. Food and Agricultural Organisation of the United Nations (FAO), Rome. ISBN 925-104637-9.

Eriksson J, Dahlin S, Nilsson I & Simonsson M. 2011. Marklära. Hungary: Elanders Hungary Kft.

Fageria N.K. 2002. Nutrient management for sustainable dry bean production in the tropics, Communications in Soil Science and Plant Analysis, vol 33, issue 9-10, pp 1537-1575.

FAO-STAT. 2013. Food and Agricultural Organization of the United Nations – Statistics Division. Available online at: http://faostat3.fao.org/home/E [Accessed 6th of May]

FAO-UNESCO 1977. Soil Map of the World. Volume VI Africa. Paris: Unesco.

Francis C.A, Flor C.A, Prager M & Sanders J.H. 1978. Density Response of Climbing Beans in two Cropping Systems. Field Crops Research, vol 1, pp 255-267.

Francis C.A & Sanders J.H. 1978. Economic Analysis of Bean and Maize Systems: Monoculture versus Associated Cropping. Field Crops Research, vol 1, pp 319-335.

Gepts P. & Debouck D. 1991. Origin, domestication, and evolution of the common bean. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 7-53.

Giller K.E. 1991. Nitrogen fixation in tropical cropping systems. 2nd Ed. Guildford and Kings's Lynn, UK, Biddles Ltd.

Graham P.H & Ranalli P. 1997. Common bean (Phaseolus vulgaris L.). Field Crops Research, vol: 53, pp 131-146.

Groenevelt P.H, Grant C.D & Semetsa S. 2001. A new procedure to determine soil water availability. Australian Journal of Soil Research, Vol 39, pp 577-598.

HLPE. 2013. Investing in smallholder agriculture for food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Jaetzold R & Schmidt H. 1982. Farm Management Handbook of Kenya – Natural Conditions and Farm Management Information - Vol IIA West Kenya Nyanza and Western Province. Rossdorf. Ministry of Agriculture Kenya in Cooperation with the German Agricultural Team (GAT) of the German Agency for Technical Cooperation (GTZ).

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M. , Zougmore R., (eds.), 2013, Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg.

Kenya National Bureau of Statistics. 2010. The 2009 Kenya Population and Housing Census – Vol I A Population Distribution by Administrative Units. Available online at: http://www.knbs.or.ke/index.php?option=com_phocadownload&view=category&id=109:population-and-housing-census-2009&Itemid=599 [Accessed 26th of August 2015]

Kenya Seed Company Limited. Seed Catalogue. [Broschure] Received by email directly from Kenya Seed Company 13th of May 2015.

Legume CHOICE. 2015. Available online at: http://legume-choice.wikispaces.com/Project+overview [Acessed 8th of November 2015].

Minitab Inc. (2007). Minitab Statistical Software, Release 15 for Windows, State College, Pennsylvania

Niringye C.S, Ssekambembe C.S & Kyamanyawa S. 2005. Effect of Plant Population on Yield of Maize and Climbing Beans Grown in an Intercropping System. African Crop Science Journal, Vol 13, No 1, pp 83-93.

Oborn I, Muriuki J, Shiluli M, Ochinga T and Okeyo I. 2015. Current Contributions to Rural Livelihoods in Kisii and Migori counties of Kenya – Quick Baseline Survey. Unpublished material. Legume CHOICE. Available online at: http://legume-choice.wikispaces.com/file/detail/Baseline+Survey+Report.rar [Acessed 8th of November 2015]

Raemakers L, Micheni A, Mbogo P, Vanderleyden J & Maertens M. 2012. Adoption of Climbing beans in the central highlands of Kenya: An empirical analysis of farmers' adoption decisions. African Journal of Agricultural Research, Vol 8, No 1, pp 1-19.

Reece, J B., Urry, L A., Cain, M L., Wasserman, S A., Minorsky, P V. & Jackson, R B. (2011.) Campbell Biology. 9th ed. Boston: Pearson Education Inc.

Reeuwijk L.P van. 2002 (ed.). Procedures for Soil Analysis. 6th ed. Tech. Pap. 9, ISRIC, Wageningen

Salami A, Kamara A.B & Briziova Z. 2010. Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities. Tunis. African Development Bank Group Working Paper Series. No 105

Schwartz H.F, Colorado State University & Langham M.A.C, South Dakota State University. Legume ipmPIPE Diagnostic Pocket Series. Legume ipmPIPE. [Broschure]. Available online at: www.ncipmc.org/action/Legume Diagnostic Cards 4.pdf [27th of April 2015]

Shellie-Dessert K.C & Bliss F.A. 1991. Genetic improvement of food quality factors. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 649-677.

Singh S.P. 1991b. Bean genetics. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 199-286.

Singh S.P. 1991a. Breeding for Seed yield. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 383-443.

Smartt J. 1990. Grain Legumes – Evolution and Genetics. Cambridge, Cambridge University Press.

Thung M. 1991. Bean agronomy in monoculture. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 737-834.

Vaz C.M.P, Manieri J. M, de Maria I.C & Tuller M. 2011. Modeling and correction of soil penetration resistance for varying soil water content. Geoderma, Vol 166, Issue 1, pp 92-101.

Voss J. & Graf W. 1991. Onfarm Research in the Great Lakes Region of Africa. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 891-929.

Voysest O. & Dessert M. 1991. Bean cultivars: classes and commercial seed types. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 119-162.

Vågen T-G, Winowiecki LA, Tamene Desta L, Tondoh JE (2015) The Land Degradation Surveillance Framework (LDSF) - Field Guide v4.1. World Agroforestry Centre, Nairobi, Kenya, pp 14.

White J. W & Izquierdo J. 1991. Physiology of yield potential and stress tolerance. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 287-382.

Woolley J, Ildefonso R.L, de Aquino Portes e Castro & Voss J. 1991. Bean cropping systems in the tropics and subtropics and their determinants. I: Schoonhoven A. van & Voysest O. (ed), Common beans: research for crop improvement. Chippenham: Antony Rowe Ltd, pp 679-706.

World Agroforestry Centre (ICRAF). 2014. Report on Focus Group Discussion in Kisii and Migori counties of Kenya. Unpublished material. Legume CHOICE. Available online at: http://legume-choice.wikispaces.com/file/detail/FGD+Report.docx [Acessed 8th of November 2015]