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*Full Length Research Paper*

# Adoption of climbing beans in the central highlands of Kenya: An empirical analysis of farmers' adoption decisions

**Lara Ramaekers[1], Alfred Micheni[3], Paul Mbogo[3], Jozef Vanderleyden[1]* and Miet Maertens[2]**

[1]Centre of Microbial and Plant Genetics, Department of Microbial and Molecular Systems, KU Leuven, Leuven, Belgium.
[2]Division of Bio-economics, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium.
[3]Kenyan Agricultural Research Institute (KARI), Nairobi, Kenya.

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**Common bean represents the second staple crop in the Kenyan highlands. Decreasing yields and overpopulation in this area demand an intensification of food production. The Kenyan Agricultural Research Institute (KARI Embu) has been promoting improved climbing bean varieties in order to boost yields. To quantify the impact of this work, a survey was done in order to (i) assess awareness, trial and adoption rates of climbing beans by local farmers and (ii) acquire insight in this adoption process. This more detailed analysis of the various adoption stages is the paper's unique contribution to the adoption literature. At the time of the survey, 90% of the farmers were aware of climbing beans, about 40% had grown climbing beans on their farms at least for one season (test/trial) and only about 11% had maintained its production (adoption). Climbing beans seem to be more popular at higher altitudes where they are grown on small areas. Increasing age of the household head, contact with extension services and farmer-to-farmer transmission are important for awareness and testing climbing beans. A serious limitation for both trial and adoption is the poor availability of seed. From this study, recommendations were made on how to improve climbing bean awareness, trial and adoption.**

**Key words:** Climbing bean, technology diffusion, technology adoption, farm-household survey, Heckman two-stage procedure, Kenyan highlands.

## INTRODUCTION

The central Kenyan highlands are characterized by a rapidly growing population with over 1000 people per $km^2$ thereby causing land fragmentation, over-cultivation and declining soil fertility which eventually leads to decreasing yields and decreasing food security (Government of Kenya, 2001; Mugwe et al., 2008). There is a pressing need to intensify food production in this region. One possible way to achieve higher yields and increase food availability is the promotion of climbing bean cultivation.

Common bean (*Phaseolus vulgaris* L.) represents the second most important staple crop in the Kenyan highlands, after maize. Beans are grown by over 95% of farmers in the region, providing over 65% of the protein and 35% of the caloric intake (CIAT, 2004). Mainly bush beans are grown, using varieties introduced by the Kenyan Grain Legume Project (GLP) in 1984. The introduction of climbing beans in this area entails a high potential as substitute of or complement to bush bean production due to its specific characteristics.

The most outstanding characteristic of climbing beans is their high yield potential: up to 4 to 5 tons/ha versus 3 tons/ha for bush beans under optimal conditions (CIAT, 2004). This allows significant climbing bean harvests,

*Corresponding author. E-mail: jozef.vanderleyden@biw.kuleuven.be. Fax: +32 16 32 19 63.

even on very small plots such as backyard gardens (Sperling and Muyaneza, 1995). Typical for climbing beans is their staggered harvesting which is more labor intensive but increases and smoothens the availability of food throughout the growing season as green leaves, pods and fresh or dry grain can be consumed (Sperling et al., 1992). Moreover, their wealthy biomass can be used as fodder for animals or may provide ground cover, control weeds and contribute to soil organic matter when not all leaves are harvested. Climbing bean cropping systems are classified as monoculture or intercropping (Woolley and Davis, 1991). Inter-cropping involves growth in association with other crops (especially maize and banana), either in relay or simultaneous planting, with the other crop providing support for the climbing beans. In monoculture, climbing beans are planted with the support of wood or bamboo stakes (mostly in Africa) or trellis systems (widespread in Andean region). Due to its labour intensity and high yield potential, climbing beans entail a high potential in land-scarce but labour-abundant regions, such as the Kenyan highlands. Some disadvantages of climbing beans perceived by farmers are (i) the longer growing period (4 months compared to 3 months for bush beans), (ii) sensitivity to drought and (iii) increased labour requirements for staking and bird scaring as climbing beans are easily attacked by birds (Sperling et al., 1992; CIAT, 2004; personal communication, KARI Embu).

Since the introduction of climbing beans in the central Kenyan highlands, no quantitative research in this area has been done to assess current diffusion and adoption rates[1] and analyse the determinants of farmers' decision to adopt –or not. In this paper, we present a quantitative adoption analysis and address three sets of central research questions: (i) what are the diffusion and adoption rates of the introduced climbing bean varieties in the central Kenyan highlands; (ii) why do some farmers try growing climbers while others do not and (iii) why do some adopt climbing beans while others stop growing climbers? Identifying the answers on these research questions is important to formulate policy recommendations to increase the diffusion and adoption of climbing beans in this region.

To address these questions, we implemented a quantitative survey among a representative sample of 595 farm-households in the region and collected detailed information on the adoption and cultivation of climbing beans. We use the survey data to estimate a statistical model of technology adoption. Most of the empirical models in the technology adoption literature estimate a dichotomous adoption decision, adoption or non-adoption, using logit or probit models (Feder et al., 1985; Kaliba et al., 2000; Sunding and Zilberman, 2001; Doss, 2006; Chianu et al., 2007; Ojiako et al., 2007; Agwu et al., 2008; Udoh and Omonona, 2008; Saka and Lawal, 2009). Such an approach ignores the multi-stage procedure of farmers' decision-making process (Dimara and Skuras, 2003). Alternative approaches have been developed by Diagne (2006) and Diagne and Demont (2007) who consider a two-stage decision process and analyse farmers' 'exposure to' and 'adoption of' new rice varieties in Western Africa, correcting for selection bias due to non-exposure in the adoption model by using an average treatment effects method. In this paper, we consider three stages in farmers' decision-making on technology adoption: (1) awareness of climbing beans; (2) trial of climbing bean production on the own farm, and (3) adoption of climbing beans. We do so because a substantial proportion of the examined population does not continue growing climbing beans after a trial period of one season. We estimate the probability at each stage and correct for selection bias at the 'trial' and 'adoption' stage using a Heckman two-stage procedure. Using this approach, it is possible to acquire a more realistic idea about the entire adoption process and to identify the main factors of interest at each level of adoption.

## MATERIALS AND METHODS

### Historical background

For centuries, climbing beans have been part of traditional agricultural systems in medium to high altitude regions (2000 to 2800 m above sea level) of the Andes and Central America (Voysest, 2000). In 1984, improved climbing bean varieties from CIAT (International Centre of Tropical Agriculture, Colombia) were officially released and promoted in Rwanda (Sperling and Muyaneza, 1995) and gradually spread to neighboring countries, including Kenya. In 1995, six climbing bean varieties (Table 1) were introduced to KARI Embu, one out of the 25 Kenyan governmental institutes for agricultural research which is located in the town Embu, the provincial headquarters of Eastern province in Kenya. The mandate region of KARI Embu covers eight districts in the central highlands of Kenya. Between 1995 and 2002, the varieties were exposed to participatory testing on-farm and on-station and sold by KARI Embu and local extension services to more than 7000 farmers. Due to marketability problems of these six varieties as reported by farmers, a new collection of mid-altitude climbers (MAC) was introduced from CIAT to KARI Embu in 2002. These climbers were designed by CIAT to be early maturing and more heat tolerant (Blair et al., 2007). Participatory testing led to the selection of five varieties which were sent to the Kenyan National Performance Trials (NPTs). This resulted in official release of 3 varieties (MAC13, MAC34 and MAC64; Table 1) by the Kenyan ministry of agriculture in 2008. Currently, KARI-Embu has embarked on seed bulking of these 3 climbing varieties. The bulked seed is constantly disseminated to farmers and other partners through centre visits on a limited scale, field days, on-farm trials or demonstrations, agricultural shows and farmer-to-farmer exchanges.

### Description of study area

The study area includes two districts, Embu and Kirinyaga, on the

[1]We use the concepts of technology diffusion and adoption as in Diagne and Demont (2007). Technology diffusion refers to the extent of knowledge and awareness of the technology among farmers in the population. Technology adoption refers to the actual use of the technology at the individual farm level as well as at the aggregate population level.

**Table 1**. List of climbing bean varieties disseminated by KARI Embu in the central Kenyan highlands.

| Variety | Farmers' name | Seed size and shape | Seed colour | Origin period |
|---|---|---|---|---|
| G2333 | Umubano | Small, round | Dark red | |
| G685 | Vuninkingi | Small, round | Bright red | |
| Flor de Mayo | Flora | Intermediate, round | Purplish/pink, cream | Rwanda |
| G20797 | Gisenyi | Intermediate, kidney | Pink/cream with black stripes | 1995-2002 |
| / | Ngwinurare | Large, kidney | Red | |
| G3323 | Puebla | Small, round | Yellow | |
| MAC13 | / | Large, kidney | Mottled cream and red | CIAT[a] |
| MAC34 | / | Large, wedge | Mottled bright red and cream | from 2002 |
| MAC64 | / | Medium, wedge | Mottled dark red and cream | |

[a]CIAT: International Centre of Tropical Agriculture, Cali, Colombia.

eastern slopes of Mount Kenya (Kenya). The districts are part of the mandate region of KARI Embu covering a total of about 88,000 households. In these two districts, only the upper midland zones (UM1 – UM2 – UM3 in Figure 1) are considered as they are the main agro-ecological zones suited for common bean production. The altitude of the study area ranges from about 1200 to 1900 m above sea level. The region has an annual mean temperature of 20°C and average annual rainfall ranging from 800 to 1200 mm with two main rainy seasons, the 'long rainy season' from March to May and the 'short rainy season' from October to November (Veldkamp et al., 2009). Rainfall increases and temperature decreases with altitude (Gachimbi, 2002; Veldkamp et al., 2009). On the slopes of Mount Kenya, a dense network of small rivers flows down, incising the surface of the slopes and shaping the zone into a system of alternating ridges and depressions. The dominant soil type consists of humic nitisols which are highly weathered and well drained tropical soils with high clay contents. Other minor soil types in the region are andosols, cambisols, acrisols and regosols. pH decreases with increasing altitude and ranges from pH 4.4 in UM1 to pH 5.6 in UM3 (Veldkamp et al., 2009).

Both districts are characterized by a high and increasing population pressure with more than 700 people per $km^2$ and annual population growth rates of 2.57% (Veldkamp et al., 2009). The inhabitants of Embu district, called Embu, represent a minor tribe in Kenya while Kirinyaga district is inhabited mainly by the ethnic majority Kikuyu tribe. Because of the relatively fertile nitisols, both districts have a high agricultural potential. Mixed farming systems are common with tea (UM1; *Camellia sinensis*), coffee (UM1 and UM2; *Coffeaarabica*) and macadamia nuts (*Macadamia ternifolia*) as the main cash crops. Main food crops are maize (*Zea mays*) and beans (*Phaseolus vulgaris*) and to a lesser extent bananas (*Musa sp*.), irish potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihotesculenta*) and a variety of fruits and vegetables mainly grown for subsistence consumption. Also zero-grazing dairy farming is important, especially in the higher, cooler and humid areas. Despite a high agricultural potential, poverty rates in this region are high, more than 30%, and increasing (Kathuthu et al., 2005).

### Sampling frame and survey data collection

The target population for this study consists of all farm-households living in Upper Midland 1, 2 and 3 zones (principal bean growing area) of Embu and Kirinyaga districts. Sampling was done for each district separately using a four-stage sampling design with divisions as primary sampling unit, sub-locations as secondary sampling unit, villages as tertiary sampling and households as ultimate sampling unit.

Stratified random sampling was applied at each stage, except for the last stage, to make sure that locations where climbing beans were promoted are included in the sample. Divisions, sub-locations and villages (primary, secondary and tertiary sampling units respectively) were stratified according to whether they were previously targeted for promotion of climbing beans or not. At each of three initial stages and in each stratum, random sampling was performed with the number of selected units per stratum proportional to its population size. In the last stage, households were randomly selected for each village using pre-established household lists wherever available. When lists were not available, households were selected as dispersed as possible and making sure to cover the entire area of the village. In this way, a self-weighting sample of 550 households in 36 villages was obtained with the number of households selected per village proportional to the village population size and ranging from 12 to 18. This sampling frame ensures our data are representative for the entire study area and allows making population inferences.

The survey was implemented using a structured questionnaire including sections on (i) household and farm characteristics, (ii) bush bean production (if any) and iii) climbing bean production (if any). The interviews were carried out in the period March-May 2010 by four technical assistants from KARI Embu, who managed the local dialects. Field assistants (village elders) residing in the area helped in locating the households and introducing the enumerators. To ensure quality and comparability of the data gathered by the four enumerators, a training was organized and the questionnaire was pre-tested before the actual start of the interviews. Additionally, afterwards, a total of 45 climbing bean adopters located in various villages in Embu district were selected and interviewed in order to increase the total number of this relatively small group for descriptive analyses of climbing bean production.

### Statistical data analysis

The survey data were digitized into an SPSS database and cleaned in order to detect and eliminate entry errors in the database. A first descriptive statistical analysis was performed to classify and characterize the adoption levels of climbing beans and to analyse the climbing bean production system. Analysis of variance (ANOVA) was applied to test for differences in the characteristics across various adoption levels. In a subsequent causal statistical analysis using STATA, a probit model and a Heckman probability model are estimated to reveal the factors that influence the likelihood of being aware of, trying out and adopting climbing beans. The extra group of 45 adopters who were selected and

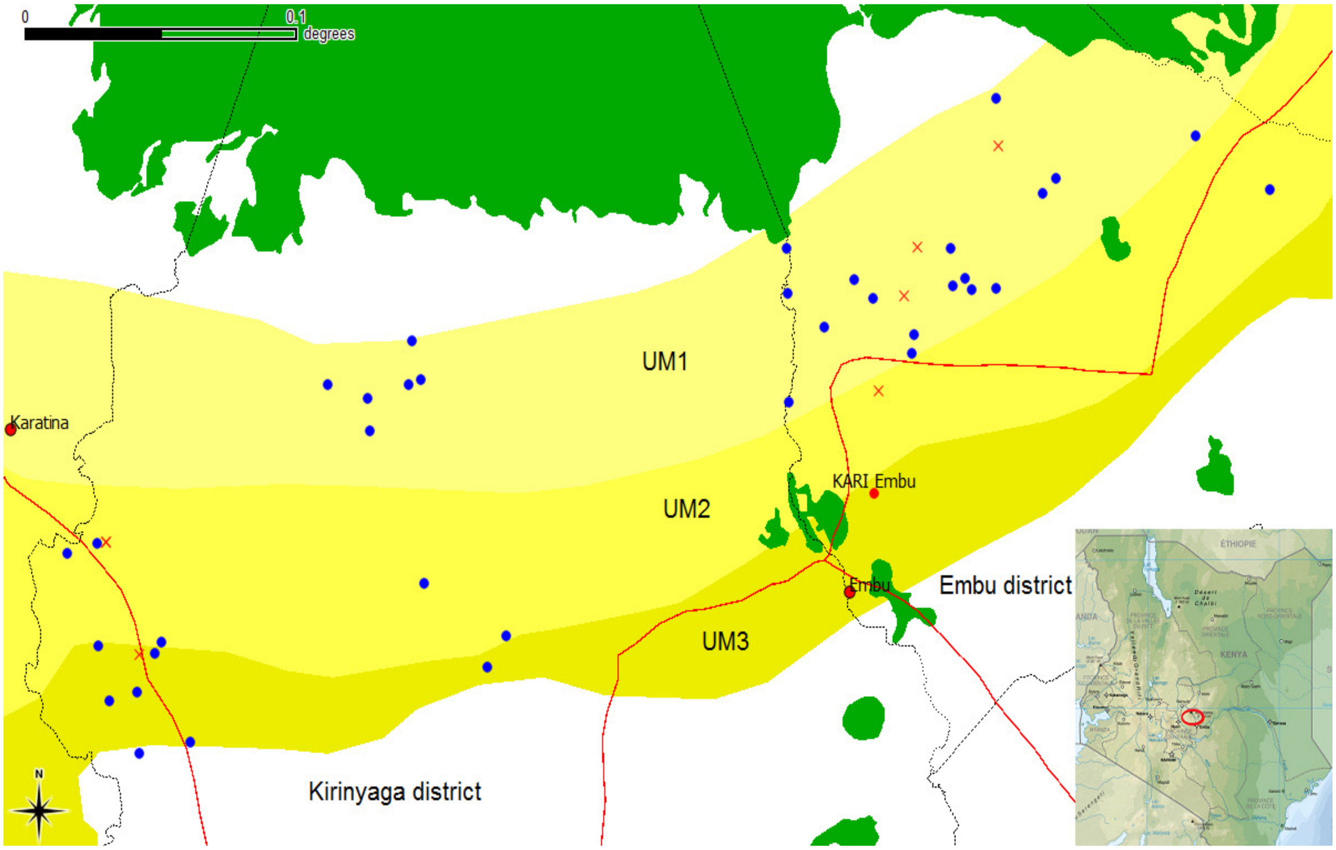



**Figure 1.** Map of Kirinyaga and Embu districts showing the location of the villages (blue dots) included in the survey. Black dotted line: District boundaries; red line: Main roads; red dots: Main towns; red crosses: Main market areas; green area: Forest; yellow areas: Agro-ecological zones with Upper Midland 1 (UM1), Upper midland 2 (UM2) and Upper Midland 3 (UM3) (qGIS, 2011).

interviewed to increase the number of adopters, were only used for descriptive analyses of climbing bean production.

## RESULTS

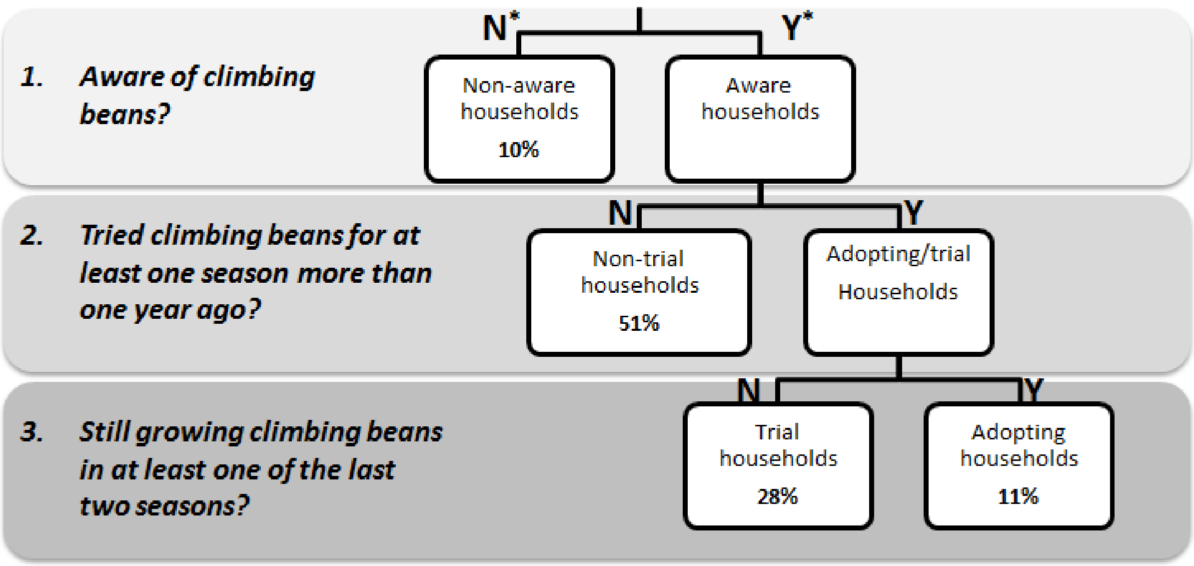
Here, we discuss the results of the descriptive and causal statistical analysis on climbing bean diffusion and adoption in the study area. First, we unravel farmers' technology adoption decision process in three stages and categorize farm-households in four classes according to the decision outcomes in these three stages. We then insert a short description of climbing bean production by trial and adopter farmers. Subsequently, we describe and compare farm and household characteristics across the four household classes. Finally, multivariate probit and Heckman probability models were developed and estimated to identify the factors determining each of the three stages in the adoption decision-making process of farmers.

### Describing the adoption decision process

To examine farmers' decision to adopt climbing beans we build on and adapt the innovation adoption theory of Rogers (2003) who describes the process of innovation adoption in five stages: (1) knowledge, (2) persuasion, (3) decision, (4) implementation and (5) confirmation. In the first stage, farmers become aware of a new technology. We call this the stage of 'awareness'[2]. In the two subsequent stages of Rogers, interested farmers look for more information on the technology, weigh the costs and benefits, and decide whether or not to try implementing the technology. These stages are empirically hard to observe and our survey data are completely uninformative about these stages. We only empirically observe whether farmers have implemented the new technologies on their field. Our second stage is therefore 'trial'. This corresponds to Rogers' implementation stage in which the decision-maker actually uses the innovation and considers its usefulness. We call this a 'trial' stage, rather than 'implementation' stage. In a final stage, farmers decide, after having tried climbing bean varieties on their field, whether or not to continue growing them and really adopt the technology. We call this the 'adoption' stage, rather than the 'confirmation' stage. This three-stage decision process, including (1) awareness, (2) trial and

[2] Others have called this 'exposure' (Diagne, 2006; Diagne and Demont, 2007).

**Table 2.** Decision tree used to assign each household to one of the four types: Non-aware, aware, trial and adopter households.




*Y = Yes, N = No

| | |
|---|---|
| Adopter household: | Household that planted climbing beans on the farm at least for one season in the past (more than two seasons ago) AND has been planting climbing beans during at least one of the last two seasons at the time of the survey. |
| Trial household: | Household that planted climbing beans on the farm at least for one season in the past, but has not been planting climbing beans anymore during the last two seasons at the time of the survey. |
| Non-trial household: | Household that has heard of climbing beans but has never planted them on the farm. |
| Non-aware household: | Household that has never heard of climbing beans. |

For each type, the % of farmers is indicated. Below this tree, definitions of the four household types are given.

(3) adoption, is graphically depicted in Table 2 and results in the identification of four types of farm-households. First, non-aware households are households that have never heard about climbing beans. Second, non-trial households are aware of the technology but have never tried cultivating climbing beans on their farm. Third, trial households have planted climbing beans on their farm at least during one season in the past (more than two seasons ago) but did not continue growing them in any of the last two seasons. Fourth, adopter households have grown climbing beans at least during one season in the past (more than two seasons ago) and have continued growing them in at least one out of the two last seasons at the time of the survey.

From our sample, we estimate that the total awareness among selected farmers is 90%, the trial rate is 39% and the adoption rate is 11% (Table 2). As our sample is representative for the population in the two surveyed districts, these results can be extrapolated to the entire population of the two districts. This means that the awareness among selected farmers (90%) can be understood as the technology diffusion rate in the area. The population trial rate is between 39% (if non-aware households have a zero probability to try out climbing beans) and 43% (=215/495 if non-aware households would have the same probability to try out climbing beans). Finally, the population adoption rate is between 11% (if non-aware and non-trial households have a zero probability to adopt) and 28% (=62/215 if non-aware and non-trial households would have the same probability to adopt as trial households). It can therefore be concluded that climbing beans are widely known throughout the study area, that on average 40% of all farmers have tried this crop at least during one season and that comparatively few farmers (11 to 28%) actually adopted climbing beans.

Trial and adopter farmers were asked in which year they started growing climbing beans. In Figure 2, the adoption rates (%) for trial farmers (blue curve), adopter farmers (black curve) and the sum of these two groups (red curve) are shown per year. It can be observed that in the period 1995 to 2004, there is a significant number of trial farmers, but actual adoption is relatively low. From the year 2004, both trial and adoption rates show a steep increase. Most farmers who were adopters at the time of the survey adopted climbing beans from the year 2006,

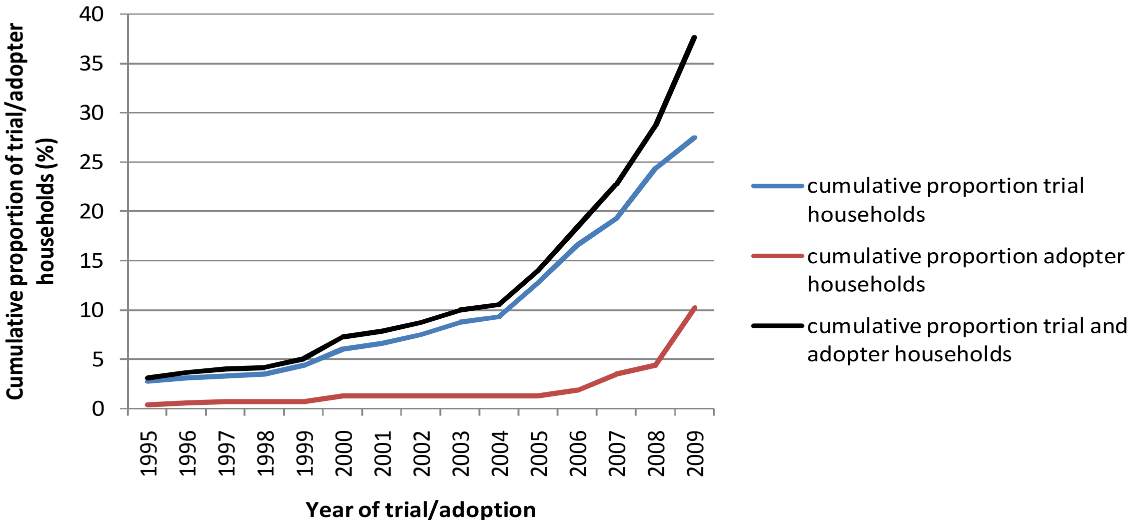



**Figure 2.** Trial/adoption rates (%) for adopter households (red curve), trial households (blue curve) and both adopter and trial households (black curve) per year. The time period shown is from 1995 (starting year of climbing bean promotion) till 2009 (one year before the survey).

especially in 2008 and 2009. These farmers who were categorized as being adopters at the time of the survey might still disadopt climbing beans after the survey. Hence, both trial and adoption are on the increase since 2004 but it is not known whether adoption which is increasing since 2006, will actually continue its increase.

Most farmers first became aware of the existence of climbing beans through other farmers (69%). Other cited sources of information on climbing beans are the extension staff (14%), the research centre KARI Embu (6.5%), relatives (5.5%) and radio (4%). In Embu district, about 10% of the farmers were informed by KARI Embu while in Kirinyaga district, this was only 3%.

The main reason for farmers to never having grown climbing beans is the unavailabilty of seed (42%). Other minor reasons are: (i) too labour intensive (10%) and (ii) no interest (12%), lack of knowledge about how to grow climbing beans (8%), lack of staking material (6%) and lack of space (4%). The main reason for farmers to abandon climbers after having tried is also the unavailability of seed (39%). Other minor reasons are: (i) too labour-intensive (22%), (ii) lack of staking material (7%), (iii) attack by birds (6.5%) and sensitivity to drought (3%). Labour intensity and attack by birds have also been reported in other studies to limit adoption of climbing beans (Sperling et al., 1992; CIAT, 2004).

## Statistical description of improved climbing bean production

In this paragraph, climbing bean production by the groups of trial and adopter farmers is described. About 65% of the persons managing the climbing bean crop on the farm was female. Compared to management of bush beans (80% female farmers), female contribution in climbing bean production was lower. Climbing bean seed for first time planting was obtained mainly as a gift or exchange with other farmers (60%) or with relatives (6%). Part of the farmers received seed directly from KARI Embu (13%) or through extension workers (11%). A few farmers bought climbing bean seed on the market (4%) or from other farmers (4%).

Most farmers planted only one climbing variety. A minority planted two (16%), three (15%), four (1.5% - four farmers) or even five varieties (0.4% - 1 farmer). The majority of the group of adopter farmers (86%) planted climbing beans during October rains 2009 while during April rains, only 52% of this group planted climbing beans. When looking at popularity of the several climbing bean varieties (Figure 3), Vuninkingi is by far the most popular variety (39%) followed by Umubano and Gisenyi (about 20% each). The climber Ngwinurare was not used by adopters. The more recently introduced varieties which are the Mid-Altitude Climbers (MAC) are only limitedly known and adopted by farmers in the central highlands of Kenya (2 to 5% adoption rate).

The total area of the plots planted with climbing beans were relatively small with 106±31 $m^2$ on average for October rains (median is 25 $m^2$) and 105±25 $m^2$ for April rains (median is 31 $m^2$). Total land areas ranged from 0.5 to 2400 $m^2$ and 0.5 to 1000 $m^2$ for October and April rains respectively. Most farmers (94%) used stakes as support for their climbing beans on the field. Very few farmers did not use any support (3%) and some farmers used permanent fences (2%). Stakes had lengths of 1.83 meters on average with about 63% of the farmers who used stakes that were not sufficiently long (shorter than 2 m). About 21% of the farmers even used stakes shorter than 1.50 m. Stakes were mainly obtained from the farm

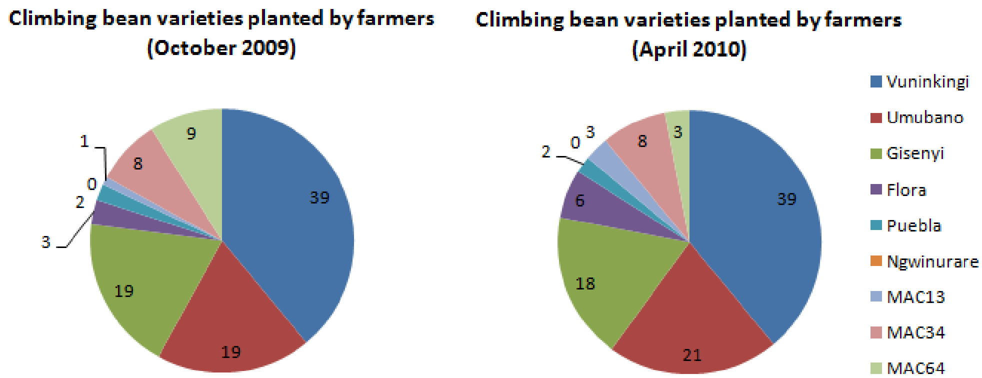



**Figure 3.** Climbing bean varieties planted by the group of adopters during October rains 2009 (left) and April rains 2010 (right).

(92%) or were bought (5%). Climbing beans were staked on average at 2 weeks with a range from 0 to 4 weeks as is recommended for climbing bean production. Most climbing beans were planted as a single crop on the field (88%) while some farmers intercropped climbing beans with maize (8%), coffee or bush beans (1% each). For October rains, the median of yields for climbing beans according to farmers was 1333 kg/ha.

Farmers were asked to list the several uses of climbing beans on their farm and to order these uses according to their importance. The primary use of climbing beans is home consumption of the dry seed (75%). Other main uses are consumption of green pods (18%) and selling the dry seed (3%). The second function of climbing beans according to farmers is consumption of green pods (35%) and the use as fodder for their animals (22%). About 10% of the farmers also consume the leaves of climbing beans. The third use as indicated by the farmers is again the use as animal fodder (47%), consumption of green pods (19%), exchanging the seed (16%) and selling it (9%). The few farmers who ever sold the dry seed, reported relatively high market prices and good appreciation of the seed by the buyers.

The main advantages of climbing beans according to the farmers are their high yielding capacity (53%), their sweet taste (18%), the need of only a small land area (3%), fast cooking (5%) and more tolerant to heavy rains and wet soils (2%). A total of 41% of the farmers could not think of any disadvantages related to climbing beans. The other farmers considered the need for staking (12%) and susceptibility to bird attack (11%), due to the sweet taste of leaves, pods and seed, as the main drawbacks of climbing beans.

Farmers were asked to give a value judgment (on a 1 to 5 scale with 1 being bad and 5 very good) for several characteristics related to climbing bean production. The yield, seed colour and taste of climbing beans were considered as good to very good. Storage capacities of the seed were considered as fair. Improvement of soil fertility by the climbing bean crop was noticed by about 60% of the farmers while 27% did not see any effect on soil fertility. In a participatory evaluation study by KARI Embu (Muthamia et al., 2003), farmers also observed better performance of their maize crop grown where climbing beans were previously planted. Tolerance to diseases and drought were rated as being average to good. In general, climbing beans have a growing season which is extended by 2 to 4 weeks compared to bush beans. Most farmers however did not consider this longer growing season as an important disadvantage. The labour requirements in the field were rated as intensive to very intensive by 19% of the farmers. The remainder estimated that the amount of labour was not especially higher for climbing beans. This result might indicate that adopter farmers do not perceive climbing bean production to be labour intensive which is contradictory to the initial hypothesis that climbing beans are labour intensive and to earlier reports on farmers' appraisal of climbing beans (Sperling et al., 1992; CIAT, 2004). Most farmers agreed that climbing beans cannot be intercropped. About 25% of the farmers did consider intercropping with climbing beans as a realistic option.

## Descriptive analysis of factors influencing farmers' technology adoption decision

The technology adoption literature, especially studies focussing on the diffusion and adoption of agricultural technologies in developing countries, have stressed the importance of socio-economic and demographic attributes of the farmer or farm-household in explaining adoption decisions (Feder et al., 1985; Rogers, 2003; Sunding and Zilberman, 2001).In this literature, farmers are assumed to adopt a new technology if it increases their profits or utility. Factors that lower the cost or risk of adopting a certain technology or factors that increase the benefits of it, will likely enhance adoption. Also farmers'

**Table 3.** Description of village and household characteristics hypothesized to influence farmers' adoption technology decisions.

| Independent variable | Description |
|---|---|
| **Village level** | |
| District | District in which the village is located (0=Embu, 1=Kirinyaga) |
| Altitude | Village altitude (meters above sea level) |
| Promotion | Promotion of climbing beans by KARI Embu through on-farm experiments (no=0, yes=1) |
| Distance | Distance from KARI Embu by car (in minutes when driving) |
| **Household level** | |
| ***Demographic variable*** | |
| Age_hh | Age in years of the household head |
| Gender_hh | Gender of the household head (male=0, female=1) |
| Dependency_ratio | Total number of persons from the household younger than 15 proportional to the total number of persons from the household |
| ***Human capital*** | |
| years_school | Total number of years the household head went to school |
| labour_endowment | Total number of persons from the household older than 16 years |
| *Physical capital* | |
| Income | Main source of cash income for the household (farm produce sales=0, other=1) |
| Land size | Land size owned by the household (acres) |
| TLU | Livestock size (Tropical Livestock Unit*) |
| non_mot_vehicle | Household owns at least one non-motorized vehicle (bicycle, cart or wheelbarrow; no=0, yes=1) |
| mot_vehicle | Household owns at least one motorized vehicle (motorcycle or motorcar; no=0, yes=1) |
| ***Social capital*** | |
| Farmer_group | Membership of a farmer group (no=0, yes=1) |
| Visit_extension | Total number of visits by extension staff on the farm in the past year |
| Visit_events | Total number of visits to agricultural events in the past year (show, training, field day, baraza) |
| Farming_info | Sources of information on farming (radio, extension, other farmers, other; no=0, yes=1) |
| nr_farming_info | Number of sources used to obtain information on farming |

*Sum of livestock units using 1 per cow; 0.8 per donkey and 0.2 per pig, sheep or goat.

preferences towards consumption or leisure, which might be strongly related to the demographic structure of the farm-household, may play a role. In addition, farmers may face constraints, most importantly capital constraints that may hinder needed investment to adopt the new technology. Previous empirical studies on technology adoption in general (Godoy et al., 1998; McDonald et al., 2003) and on climbing bean adoption in Africa in particular (Sperling et al., 1992; Grisley, 1994; Sperling and Muyaneza, 1995; Musoni et al., 2001; CIAT, 2004) have shown that the following factors may play a role in explaining farmers' technology adoption decisions: (1) age was shown to be a factor with a positive impact on adoption meaning that older, more experienced farmers were more likely to adopt new technologies; (2) promotion of new technology through farmer-managed, on-farm field experiments has proven to be an effective but limited method for diffusing new varieties; (3) higher labour endowments would facilitate the decision to test and adopt a new technology; (4) a higher level of education has shown to stimulate amenability to innovation and provide better access to information; (5) small land sizes could give incentives to test and adopt climbing beans and (6) membership of farmers' associations was shown to positively influence adoption of new technology.

In our analysis, we focus on (1) village level variables that represent the institutional and agro-ecological setting; (2) demographic variables, including the age and gender of the household head and the household dependency ratio; (3) human capital variables, including labour endowments and education; (4) physical capital variables, including households' land and non-land assets and access to off-farm income; and (5) social capital variables, including membership of a farmers' group and access to information. These variables are described in Table 3. Average values among the four types of farmer-households were calculated for each characteristic separately and subsequently, it was tested whether there were significant differences among these types (Table 4).

**Table 4**. Village and farm/household characteristics (%) of the 4 household types of improved climbing bean varieties in the central highlands of Kenya.

| Parameter | | Adopter households | Trial households | Non-trial households | Non-aware households | |
|---|---|---|---|---|---|---|
| | | n=62 | n=153 | n=280 | n=55 | |
| **Village level** | **Total mean** | | **Means per household type** | | | **ANOVA or Welch[a]** |
| District | 0.46±0.02 | 0.15±0.04[c] | 0.33±0.04[b] | 0.60±0.03[a] | 0.69±0.06[a] | 0.000*** |
| Altitude (m) | 1568±7 | 1630±22[a] | 1622±12[a] | 1540±9[b] | 1490±21[b] | 0.000*** |
| Promotion | 0.31±0.02 | 0.35±0.06[ab] | 0.40±0.04[a] | 0.28±0.03[ab] | 0.18±0.05[b] | 0.007** |
| Distance (min) | 41±0.9 | 37±2.4[ab] | 37±1.6[b] | 43±1.3[a] | 44±2.7[ab] | 0.009** |
| **Household level** | | | | | | |
| ***Demographic characteristics*** | | | | | | |
| Age_hh (years) | 47.4±0.4 | 48.3±1.1[ab] | 49.3±0.7[a] | 46.8±0.6[b] | 44.2±1.3[b] | 0.002** |
| Gender_hh | 0.17±0.02 | 0.15±0.05 | 0.15±0.03 | 0.19±0.02 | 0.15±0.05 | 0.600 |
| Dependency_ratio | 0.29±0.01 | 0.25±0.03 | 0.28±0.02 | 0.29±0.01 | 0.29±0.03 | 0.598 |
| ***Human capital*** | | | | | | |
| Years_school | 7.6±0.2 | 7.9±0.6 | 7.7±0.3 | 7.5±0.2 | 7.4±0.6 | 0.861 |
| Labour_endowment | 3.05±0.07 | 2.84±0.18 | 3.19±0.13 | 3.05±0.11 | 2.85±0.24 | 0.431 |
| ***Physical capital*** | | | | | | |
| Income | 0.22±0.02 | 0.16±0.05 | 0.22±0.03 | 0.24±0.03 | 0.22±0.06 | 0.487 |
| Land size (acres) | 1.96±0.08 | 2.01±0.25 | 2.19±0.16 | 1.86±0.10 | 1.76±0.26 | 0.255 |
| TLU | 1.77±0.06 | 1.40±0.15[b] | 2.04±0.12[a] | 1.75±0.09[ab] | 1.46±0.19[ab] | 0.011* |
| Non_mot_vehicle | 0.69±0.02 | 0.68±0.06 | 0.76±0.04 | 0.67±0.03 | 0.60±0.07 | 0.104 |
| Mot_vehicle | 0.08±0.01 | 0.05±0.03 | 0.12±0.03 | 0.05±0.01 | 0.15±0.05 | 0.071 |
| ***Social capital*** | | | | | | |
| Farmer_group | 0.25±0.02 | 0.24±0.06[ab] | 0.35±0.04[a] | 0.22±0.03[b] | 0.16±0.05[b] | 0.016* |
| Visit_extension | 0.30±0.06 | 0.35±0.10[a] | 0.50±0.17[a] | 0.23±0.06[a] | 0.02±0.02[b] | 0.000*** |
| Visit_events | 1.13±0.09 | 1.02±0.16 | 1.32±0.18 | 1.06±0.12 | 1.06±0.34 | 0.613 |
| ***Farming_information*** | | | | | | |
| Radio | 0.76±0.02 | 0.68±0.05 | 0.76±0.04 | 0.78±0.03 | 0.80±0.05 | 0.233 |
| Extension | 0.18±0.02 | 0.36±0.05[a] | 0.15±0.03[b] | 0.14±0.02[b] | 0.11±0.04[b] | 0.000*** |
| Other farmers | 0.27±0.02 | 0.29±0.04 | 0.28±0.04 | 0.28±0.03 | 0.16±0.05 | 0.314 |
| Other | 0.06±0.01 | 0.07±0.02[b] | 0.03±0.01[b] | 0.05±0.01[b] | 0.16±0.05[a] | 0.004** |
| nr_farming_info | 1.38±0.02 | 1.59±0.07[a] | 1.35±0.04[b] | 1.33±0.03[b] | 1.35±0.07[ab] | 0.001** |

Values represent mean±mean standard error of each adoption level. [a]Levene's test was used to check equality of variances among household types. For equal variances, ANOVA and Tukey as post-hoc test for differences among each pair of groups were used. For unequal variances, Welch test and Tamhane as post-hoc test were used. Esterics indicate significance level: *0.05 > p ≥ 0.01; **0.01 > p ≥ 0.001; ***p < 0.001.

### *Characteristics at village level*

Generally, 46% of the interviewed households are from Kirinyaga district (Table 4). The proportion of trial and especially adopter households living in Embu district appears to be higher compared to Kirinyaga district (Table 4). It seems therefore that trial and particularly adoption of climbing beans are most spread in Embu compared to Kirinyaga.

For every village, altitude was recorded. There is a difference in altitude across the villages in the sample and the average village altitude for the groups of trial and adopter households is significantly higher than for the group of non-aware and non-trial households. This implies that trial and adoption are more frequent at higher altitudes.

One of the promotion and evaluation strategies for climbing beans by KARI Embuin the field are farmer-managed, on-farm field experiments. This strategy has proven to be an effective but limited method for diffusing new varieties (Grisley, 1994; Kaliba et al., 2000). From Table 4, it can be concluded that a higher proportion of trial and adopter households live in villages where promotion was done, although adopter and non-trial households were not significantly different. The group of non-aware households was least represented in villages with promotion activities by KARI Embu. This might indicate that promotion through on-farm field experiments contributes to increased awareness and trial.

The distance by car from KARI Embu to each village in minutes drive was also recorded as KARI Embu has limited financial resources and therefore mainly chooses to carry out the field activities close to the station. The results from Table 4 indicate that trial and adopter households are located closer to KARI Embu on average than the non-trial and non-aware households, although the difference between adopter households and non-trial households was not significantly different due to higher mean standard errors of these two smaller groups.

### *Demographic characteristics*

Mean age among all household heads (age_hh) was 47 years with trial and adopter households being somewhat older on average than non-trial and non-aware households. However, the difference in age between adopters and both non-trial and non-aware households was not significant.

Of all the households surveyed, 83% was male-headed. Equal proportions of female- and male-headed households can be found among the various household types implying that female-headed households are not running behind at the level of climbing bean awareness, trial and adoption.

Based on information on the number of household members and their age, the dependency ratio was calculated which estimates the relative number of dependent individuals (children younger than 16) in the household. The higher the dependency ratio in a household, the higher the need for food consumption. However, dependency ratios were not significantly different among the various household types.

### *Human capital*

Education of the household head was recorded in the total number of years this person had gone to school (years_school). In general, a higher level of education is expected to stimulate amenability to innovation and provide better access to information, that is, leaflets, brochures (Grisley and Shamambo, 1993; Udoh and Omonona, 2008). Trial and adopter households showed a slightly higher education level compared to non-trial and non-aware households although differences were not significant.

A first source of labour is the household members who are (potentially) able to work on the farm (labour_endowment). These are all the household members older than 15 years. As climbing bean adoption requires more labour, it is expected that higher labour endowments facilitate the decision to test and adopt (Sperling et al., 1992; CIAT, 2004; Sperling and Muyaneza, 1995). However, there were no significant differences for labour endowment among the various household types.

### *Physical capital*

The main cash income of most households in the regions surveyed is generated through farm produce sales (78%). Only about one in five households (22%) gets its main source of income off-farm, mainly in the private sector. It could be expected that the latter have less incentives to know and eventually to test and adopt climbing beans. No significant differences for the main source of income among the four household types are found although the group of adopters includes less farmers with off-farm incomes than the 3 other groups.

The increasing population pressure in the central highlands of Kenya causes land fragmentation and small land sizes per farm. The mean land size owned by the household was about 1.96 acres or 0.79 ha. Small land sizes could give incentives to test and adopt climbing beans as this high-yielding crop is able to generate the same yield as bush beans on a smaller land space (Sperling et al., 1992; CIAT, 2004; Sperling and Muyaneza, 1995). However, land sizes did not vary significantly among the 4 household types although trial and adopter households had higher land sizes compared to non-trial and non-aware households. Also, trial households have higher land sizes compared to adopter households although the difference is not significant.

As the climbing bean biomass can and is actually used as fodder for animals (Sperling et al., 1992; CIAT, 2004), it is expected that households with more animals (expressed in TLU or Tropical Livestock Units) have higher chances to test climbing beans and to adopt them. However, significant differences were only found among adopter and trial households with the latter group having more livestock which is against expectations.

The ownership of non-motorized vehicles and motorized vehicles by the household are both indicators for wealth. Only 8% of the households owned at least one motorized vehicle. The possession of non-motorized vehicles including bicycles, carts or wheelbarrows were more common with almost 70% of the population owning at least one non-motorized vehicle. However, these wealth indicators did not vary significantly among the four household types.

### *Social capital*

Only 25% of the farmers were member of a farmer group. Farmer groups gather regularly and these gatherings are potential sources of information on climbing beans and possibly also of seed of climbing varieties. Several adoption studies found that membership of farmers' associations positively influenced adoption of improved varieties (Ojiako et al., 2007; Chianu et al., 2007). Of the group of non-aware households, only 16% were members of farmer groups. Trial and adopter households were more frequently member of a farmer group compared to non-trial and non-aware households although only trial households differed significantly from both non-trial and non-aware households.

Contact with extension services was measured by the number of visits of an extension worker to the farm in the year before the survey. Non-aware households had significantly lower number of visits by extension compared to the other three household types implying that extension services played a role in making farmers aware of the existence of climbing beans.

Another way of possible access to climbing bean technology could be by visits to agricultural events. However, among the four household types, there was no difference in number of visits to agricultural events.

Farmers were also asked about the main sources they use to obtain information on farming. About 76% of the farmers received farming information through the radio, 27% from other farmers and 18% from extension services. The radio did not appear to play a role in spreading information on climbing beans. Remarkably, among the adopters, 35% used extension services as farming information source versus around 11 to 15% only among the other groups. This implies that adopters making use of extension services were more likely to adopt climbing beans after trial. Farmers using other sources of information, such as newspaper or television (other), were less likely to know about climbing beans.

Finally, it also mattered how many different sources on farming information were used (nr_farming_info). Adopter households used more sources compared to the other household types (although the difference with non-aware households was not significant but this is probably due to the higher mean standard errors of both groups).

## Causal analysis of farmers' technology adoption decisions

### *Description of estimated models*

For each decision level, we estimate the probability of a household to be aware of, to have tried and to have adopted climbing beans as follows:

$$P\,(\text{awareness} = 1 \mid X_i) = \Phi\,(\beta_0 + \beta_i X_i + \varepsilon) \tag{1}$$

$$P\,(\text{trial} = 1 \mid X_j\,, \text{awareness} = 1) = \Phi\,(\beta_0{}' + \beta_j X_j + \varepsilon') \tag{2}$$

$$P\,(\text{adoption} = 1 \mid X_k\,, \text{trial} = 1) = \Phi\,(\beta_0{}'' + \beta_k X_k + \varepsilon'') \tag{3}$$

where awareness, trial and adoption are the dichotomous dependent variables (0 for no and 1 for yes). The vectors of independent variables $X_i X_j$ and $X_k$ include the variables identified in Table 3, apart from nr_farming_info as this is collinear with and captured by the farming_info dummy variables. The error terms are denoted by ε, ε' and ε'' and Φ denotes the cumulative distribution function of the standard normal distribution (Wooldridge, 2001). Equations 1 to 3 describe probit models that can be estimated using maximum likelihood estimation (Wooldridge, 2001).

The decision of trial and adoption are conditional on being aware of and having tried climbing beans respectively. A problem of selection bias arises as awareness and trial are not randomly distributed across the population. This might lead to biased estimates in the probit models. We use a Heckman two-stage procedure to test and correct for possible selection bias in model 2 and 3 (Heckman, 1976, 1979; Wooldridge, 2001). A first Heckman probability model (Heckprob) is estimated, explaining trial of climbing beans among aware farm-households in the second stage and selecting aware households in the first stage. The variables defining how the farmer receives information on farming (radio, extension, other_farmers, other) are used as selection variables in the first stage selection equation. The test for possible selection bias for this Heckprob model was not significant (Likelihood-Ratio test of independent equations had a value of 2.66 with p-value 0.1027), indicating that sample selection does not bias the estimates in the adoption model. This result is likely related to the fact that awareness is quite high in the study region. As a result, we can use two independent probit regressions to estimate the probability of awareness and trial of climbing beans independently (Tables 5 and 6 respectively). In order to verify robustness of each probit regression, we estimate two slightly different specifications of the models. Model specification A includes a set of village level variables identified in Table 3 as explanatory variables while model specification B includes village dummies to correct for village level variation in institutional and agro-ecological conditions (estimated coefficients for village dummies are not shown).

A second Heckman probability model (Heckprob) is estimated, explaining adoption of climbing beans among trial farmers in the second stage and selecting trial households in the first stage. We use the variables promotion and distance to the research centre KARI Embu as selection variables in the first stage. Promotion of a new technology is important in creating awareness among farmers and in convincing farmers to try out the new technology. However, once farmers have tested the technology, they are less influenced by promotion activities and likely base their judgement and decision on whether to continue using the new technology or not on their own experience. Therefore, promotion is a good selection variable. In addition, promotion has a significant effect on trial (Table 6) but is not correlated with adoption.

**Table 5**. Parameter estimates of the probit model for the factors potentially influencing awareness of improved climbing bean varieties in the central highlands of Kenya.

| **Parameter** | **Model A (village level variable)** | | | | **Model B (village dummies)** | | | |
|---|---|---|---|---|---|---|---|---|
| Number of observations | 540 | | | | 389 | | | |
| Log-likelihood value | -145.275 | | | | -119.247 | | | |
| LR Chi-squared | 60.54*** | | | | 79.89*** | | | |
| Pseudo R-squared | 0.172 | | | | 0.239 | | | |
| **Predictor variable** | **Coef [a]** | **Std. Err.** | **dy/dx [b]** | **Std. Err. [c]** | **Coef. [a]** | **Std. Err.** | **dy/dx [b]** | **Std. Err. [c]** |
| **Village level** | | | | | | | | |
| District | -0.286 | 0.260 | -0.031 | 0.029 | - | - | - | - |
| Altitude | 0.002*** | 0.001 | 0.0002 | 0.000 | - | - | - | - |
| Promotion | 0.306 | 0.200 | 0.297 | 0.183 | - | - | - | - |
| Distance | 0.005 | 0.005 | 0.001 | 0.001 | - | - | - | - |
| | | | | | | | | |
| **Household level** | | | | | | | | |
| ***Demographic variable*** | | | | | | | | |
| age_hh | 0.020** | 0.010 | 0.002 | 0.001 | 0.034*** | 0.012 | 0.004 | 0.002 |
| gender_hh | 0.393 | 0.278 | 0.021 | 0.020 | 0.452 | 0.319 | 0.046 | 0.027 |
| dependency_ratio | 0.075 | 0.116 | 0.080 | 0.012 | 0.151 | 0.130 | 0.019 | 0.016 |
| ***Human capital*** | | | | | | | | |
| years_school | 0.018 | 0.024 | 0.002 | 0.003 | 0.015 | 0.028 | 0.002 | 0.003 |
| labour_endowment | 0.260 | 0.135 | 0.028 | 0.015 | 0.109 | 0.151 | 0.014 | 0.019 |
| ***Physical capital*** | | | | | | | | |
| Income | 0.290 | 0.221 | 0.027 | 0.0187 | 0.350 | 0.261 | 0.038 | 0.026 |
| Land size | -0.055 | 0.057 | -0.006 | 0.006 | -0.093 | 0.071 | -0.012 | 0.009 |
| TLU | 0.087 | 0.069 | 0.009 | 0.007 | 0.095 | 0.084 | 0.012 | 0.011 |
| non_mot_vehicle | 0.236 | 0.193 | 0.027 | 0.024 | 0.390* | 0.226 | 0.055 | 0.037 |
| mot_vehicle | -0.619** | 0.280 | -0.099 | 0.062 | -0.698** | 0.309 | -0.132 | 0.081 |
| ***Social capital*** | | | | | | | | |
| farmer_group | 0.259 | 0.225 | 0.028 | 0.020 | 0.297 | 0.267 | 0.034 | 0.027 |
| visit_extension | 0.693* | 0.364 | 0.074 | 0.030 | 0.884** | 0.438 | -0.117 | 0.040 |
| visit_events | -0.019 | 0.043 | -0.002 | 0.005 | -0.020 | 0.064 | 0.002 | 0.008 |
| Radio | 0.004 | 0.235 | 0.038 | 0.025 | 0.008 | 0.275 | 0.001 | 0.035 |
| Extension | 0.198 | 0.269 | 0.047 | 0.023 | 0.360** | 0.324 | 0.037 | 0.028 |
| other_farmers | 0.458** | 0.226 | 0.070 | 0.019 | 0.589** | 0.264 | 0.061 | 0.026 |
| | | | | | | | | |
| Constant | -3.949** | 1.135 | - | | -2.364** | 0.884 | - | - |

[a]Stars indicate significance level: *0.10 > p ≥ 0.05; **0.05 > p ≥ 0.01; ***0.01 > p ≥ 0.001; ****p < 0.001. [b]dy/dx is for discrete change of dummy variables from 0 to 1. [c]Standard errors for these discrete changes.

The second selection variable which is the distance to the research centre KARI Embu, is a parameter for the probability of a farmer-household to be involved in any kind of promotional activity with climbing beans and is therefore also a proper selection variable. The Heckman selection model is difficult to estimate with a large number of dummy explanatory variables; this results in problems of convergence. We therefore estimate the model only using specification A, without village dummies, and using the variable nr_farming_info instead of separate farming_info dummy variables. These results are shown in Table 7. The test for possible selection bias (Likelihood Ratio test of independent equations) is significant (value of 2.77 with p-value 0.0960), indicating that sample selection needs to be corrected by using the Heckman two-stage procedure.

### Causal analysis of farmers' technology adoption decisions

The first independent probit regression model which estimates the probability of awareness of climbing beans is shown in Table 5. The Log-likelihood value is used in the Likelihood Ratio Chi-Square test (LR Chi-squared) which tests significance of the model. The test points out

**Table 6.** Parameter estimates of the probit model for the factors potentially influencing trial of improved climbing bean varieties in the central highlands of Kenya.

| Parameter | Model A (village level variables) | | | | Model B (village dummies) | | | |
|---|---|---|---|---|---|---|---|---|
| Number of observations | 540 | | | | 525 | | | |
| Log likelihood value | -309.501 | | | | -279.984 | | | |
| LR Chi-squared | 104.48**** | | | | 134.80**** | | | |
| Pseudo R-squared | 0.144 | | | | 0.194 | | | |
| **Predictor variable** | **Coef.[a]** | **Std. Err.** | **dy/dx[b]** | **Std. Err.[c]** | **Coef.[a]** | **Std. Err.** | **dy/dx[b]** | **Std. Err.[c]** |
| **Village level** | | | | | | | | |
| District | -0.808**** | 0.187 | 0.299 | 0.066 | - | - | - | - |
| Altitude | 0.002**** | 0.000 | 0.001 | 0.000 | - | - | - | - |
| Promotion | 0.275** | 0.132 | 0.105 | 0.051 | - | - | - | - |
| distance | 0.011** | 0.004 | 0.004 | 0.002 | - | - | - | - |
| **Household level** | | | | | | | | |
| ***Demographic variable*** | | | | | | | | |
| Age_hh | 0.020*** | 0.008 | 0.008 | 0.002 | 0.029*** | 0.009 | 0.011 | 0.003 |
| Gender_hh | -0.202 | 0.188 | -0.074 | 0.067 | -0.224 | 0.200 | -0.080 | 0.069 |
| Dependency_ratio | -0.019 | 0.081 | -0.007 | 0.031 | -0.075 | 0.089 | -0.028 | 0.033 |
| ***Human capital*** | | | | | | | | |
| Years_school | 0.005 | 0.017 | 0.002 | 0.006 | 0.017 | 0.018 | 0.006 | 0.007 |
| Labour_endowment | 0.031 | 0.077 | 0.012 | 0.029 | 0.020 | 0.085 | 0.007 | 0.032 |
| ***Physical capital*** | | | | | | | | |
| Income | -0.086 | 0.156 | -0.032 | 0.058 | -0.133 | 0.173 | -0.048 | 0.062 |
| Land size | -0.001 | 0.040 | -0.000 | 0.015 | -0.022 | 0.047 | -0.008 | 0.018 |
| TLU | 0.001 | 0.046 | 0.000 | 0.017 | -0.011 | 0.050 | -0.004 | 0.018 |
| Non_mot_vehicle | 0.258* | 0.141 | 0.096 | 0.051 | 0.256* | 0.151 | 0.092 | 0.053 |
| Mot_vehicle | 0.333 | 0.232 | 0.130 | 0.092 | 0.390 | 0.250 | 0.151 | 0.099 |
| ***Social capital*** | | | | | | | | |
| Farmer_group | 0.308** | 0.145 | 0.119 | 0.057 | 0.283* | 0.160 | 0.107 | 0.061 |
| Visit_extension | 0.103 | 0.063 | 0.039 | 0.024 | 0.117* | 0.061 | 0.043 | 0.023 |
| Visit_events | -0.001 | 0.031 | -0.000 | 0.012 | 0.011 | 0.032 | 0.004 | 0.012 |
| Radio | -0.225 | 0.160 | -0.086 | 0.062 | -0.231 | 0.173 | -0.087 | 0.066 |
| Extension | 0.020 | 0.175 | 0.008 | 0.066 | -0.071 | 0.198 | -0.026 | 0.072 |
| Other_farmers | 0.054 | 0.153 | 0.021 | 0.059 | 0.002 | 0.166 | 0.001 | 0.061 |
| Constant | -4.958**** | 0.872 | - | - | -1.890*** | 0.637 | - | - |

[a]Esterics indicate significance level: *0.10 > p ≥ 0.05; **0.05 > p ≥ 0.01; ***0.01 > p ≥ 0.001; ****p < 0.001. [b]dy/dx is for discrete change of dummy variables from 0 to 1. [c]Standard errors for these discrete changes.

that both models are significant. The pseudo R-squared value (McFadden's pseudo R-squared) is a measure for goodness-of-fit of the model and indicates that model B fits the data better than model A. For each predictor variable in each model, the model coefficients, standard errors, marginal effects (dy/dx) and standard errors of marginal effects are shown.

Altitude appears to be highly significant and positively influences awareness indicating that at higher altitudes, there are more farmers who have heard of climbing beans.

The age of the household head positively influences awareness in both model A and B, implying that older households have a higher probability of being aware of climbing beans than younger households.

Also in both models, wealth of households as measured by the number of motorized vehicles owned, negatively influences awareness. Therefore, wealthy households appear to be less aware of climbing beans. In model B only, the number of non-motorized vehicles plays a role in awareness of climbing beans (at 10% probability level). This might indicate that the poorest households are less aware of the existence of climbing beans.

The number of visits by extension services made to the household appears to play a role in awareness of climbing beans. With every visit paid to a household, the chances on awareness of climbing beans increases with 7.4 or 11.7% (marginal value of 0.074 or 0.117 in model A or B respectively). Also receiving information on farming through extension services influences awareness significantly.

The second probit regression model built to explain the decision by farmers to test climbing beans or not is shown in Table 6. Both model A and B are significant. Model B fits the data better than model A as the pseudo R-squared value is higher for model B.

Both probit models A and B are very similar with the same predictor variables being significant. The variable district is highly significant indicating that in Embu, there are significantly more households who have tested climbing beans on their farm compared to Kirinyaga. Altitude is again highly significant indicating that at higher altitudes, there are more farmers who tested climbers. Also promotion by KARI Embu appears to have a significant positive influence on climbing bean trial. The distance from the village to the KARI Embu center also influences climbing bean testing in a positive way. This might be because KARI Embu center is located at low altitudes (Figure 1) and adoption appears to be higher at higher altitudes which are further away from the research center.

Age of the household head has a positive influence on climbing bean trial suggesting that older households have higher chances to test climbing beans compared to younger households. The number of non-motorized vehicles a household owns which is a measure for wealth does play a significant, positive role in the decision to test climbing beans or not. In other words, it seems that the poorest households are the ones having a smaller probability of testing climbing beans. Being member of a farmers' group plays an important role in the decision to whether or not test climbing beans. Farmers who are member of a farmers' group are 11.9 or 10.7% (model A or B) more probable of testing climbing beans as compared to farmers not being member of a farmers 'group. Also visits made by extension officers to the households play a significant, positive role in the decision to test climbing beans (the variable visit_extension is not significant in model A, but close to significance with a p-value of 0.101, while in model B, this variable is significant at 10% probability level).

According to the Likelihood Ratio Chi-Square test (LR Chi-squared), the model explaining adoption of climbing beans is significant (Table 7). The variable district is significant at 1% probability level pointing out that in Kirinyaga district there is less adoption compared to Embu district. The variable land size has a positive effect on adoption indicating that farmer households with larger land sizes are more likely to adopt climbing beans after having tested them. Another significant explanatory variable showing a negative effect is the amount of livestock owned by the household. Households with more animals are less likely to adopt climbing beans. Finally, the number of sources through which farming information is obtained influences adoption positively at 10% probability level.

## DISCUSSION

In this study, the adoption process of climbing bean varieties by farmers in the central Kenyan highlands, promoted by KARI Embu and extension services, was evaluated. The main objective is to come to a better understanding of this adoption process and to formulate useful recommendations on how to enlarge the group of farmers who are adopters of climbing beans in view of the intrinsic advantages of climbing beans.

In the central highlands of Kenya, awareness of climbing beans by farmers is high but adoption is quite low (11 to 28%). For comparison, assessment studies on adoption of climbing beans by farmers in Rwanda (Sperling et al., 1992; Sperling and Muyaneza, 1995) report overall rates of adoption increasing from under 5% in the early 1980s to 42% in 1992 and 47% in 1995. Adoption ranged between 47 and 90% in six of ten provinces that have conducive environments, or in those that were deliberately targeted by research and development projects. The main differences between the central highlands of Kenya and the success story in Rwanda might be: (i) a higher availability of climbing bean seed through research and extension (Musoni et al., 2001) and (ii) high incidence of root rot (*Fusarium oxysporum*), which severely attacked and damaged local and improved bush germplasm in farmers' fields (David et al., 2002).

The most remarkable variable playing a highly significant role for both awareness and trial is the altitude of the village. This result indicates that climbing beans are clearly more popular at higher altitudes. A possible reason could be the difference in soil and climate conditions as pH and temperature decrease and rainfall increases with increasing altitude. Therefore, at higher altitudes (mainly UM1), soils are more acidic (also observable because main zone of tea growth is UM1) and the climate is cooler with more rainfall mainly as heavy showers. Compared to bush beans, climbing beans are more suitable for these conditions and therefore, the difference in performance between bush and climbing beans will be explicitly larger at high altitudes. Additionally, as global warming makes temperatures rise, the lower regions become less suitable every day for the production of climbing bean varieties, even though the MAC-lines are considered to be heat-tolerant lines. Another potential reason for the popularity of climbing beans at higher altitudes could be the vicinity of the forest which could provide staking material. However, according to the study, 92% of the farmers obtain their stakes from their own farm and 5% buy stakes. Still, it

**Table 7**. Parameter estimates of the Heckman probability model for the factors potentially influencing adoption of improved climbing bean varieties in the central highlands of Kenya.

| | | | | |
|---|---|---|---|---|
| Total number of observation | | | 540 | |
| Censored observations | | | 328 | |
| Uncensored observations | | | 212 | |
| Log likelihood value | | | -426.435 | |
| LR Chi-squared | | | 29.28** | |
| Likelihood ratio test of independent equation | | | 2.77* | |
| **Predictor variable** | **Coef.[a]** | **Std. Err.** | **dy/dx[b]** | **Std. Err.[c]** |
| **Village level** | | | | |
| District | -0.519*** | 0.189 | 0.088 | 0.032 |
| Altitude | 0.0005 | 0.0006 | 0.0001 | 0.0001 |
| **Household level** | | | | |
| ***Demographic variable*** | | | | |
| Age_hh | 0.008 | 0.009 | 0.001 | 0.002 |
| Gender_hh | -0.191 | 0.244 | -0.029 | 0.034 |
| Dependency_ratio | -0.124 | 0.114 | -0.021 | 0.019 |
| ***Human capital*** | | | | |
| Years_school | 0.020 | 0.021 | 0.003 | 0.0034 |
| Labour_endowment | -0.051 | 0.128 | -0.009 | 0.021 |
| ***Physical capital*** | | | | |
| Income | -0.251 | 0.214 | -0.039 | 0.030 |
| Land size | 0.090* | 0.051 | 0.015 | 0.009 |
| TLU | -0.173* | 0.069 | -0.029 | 0.012 |
| Non_mot_vehicle | 0.031 | 0.176 | 0.005 | 0.029 |
| Mot_vehicle | -0.323 | 0.359 | -0.045 | 0.040 |
| ***Social capital*** | | | | |
| Farmer_group | -0.094 | 0.188 | -0.015 | 0.030 |
| Visit_extension | -0.015 | 0.084 | -0.002 | 0.014 |
| Visit_events | -0.005 | 0.049 | -0.001 | 0.008 |
| nr_farming_info | 0.087 | 0.151 | 0.015 | 0.026 |
| constant | -2.388** | 1.053 | - | - |

In order to test and correct for sample selection bias, due to unobservability of the decision to adopt or not for non-trial and non-aware households, the probit model for trial of climbing beans (Table 6) was used as a selection model with promotion and distance to the KARI center as selection variables (selection model not shown).[a]Stars indicate significance level: *0.10 > p ≥ 0.05; **0.05 > p ≥ 0.01; ***0.01 > p ≥0.001; ****p < 0.001; [b]dy/dx is for discrete change of dummy variables from 0 to 1. [c]Standard errors for these discrete changes

could be possible that also forest material is used, but as the forest is protected by Kenyan law, farmers will not mention it. Very few reported studies on agricultural technology adoption take altitude into account. A study on production constraints of banana based cropping systems in the Great Lakes region (Bouwmeester et al., 2009) revealed that biotic constraints and drought are more severe at lower altitudes. However, the altitude range in this study was much broader (430 to 1900 masl) and biotic constraints were only significantly higher at very low altitudes.

Direct promotion by KARI Embu is done on field days and agricultural shows, by organizing farmer visits to the centre, selling limited amounts of seed at the centre and by setting up experimental fields on-farm which are also used as demonstration plots. A significant effect of these promotional activities on trial of climbing beans could be observed in this study. Farmers living in villages where promotional activities were carried out, have a 10.4% higher chance of testing climbing beans. Also indirect promotion of climbers by KARI Embu was done through collaboration with extension services which have an elaborate and dense, rural network. The effect of extension services is observable both at the level of creating awareness and of climber testing. The approach of collaboration with extension services therefore seems to be a very fruitful strategy. Many other adoption studies report a significant positive effect of contact with extension services on adoption of new technologies (Kaliba et al., 2000; Ojiako et al., 2007; Udoh and Omonona, 2008;

Saka and Lawal, 2009).

The role of farmer-to-farmer transmission seems to be important both at the level of creating awareness and of testing climbing beans. Most of the farmers (69%) first heard of climbing beans through other farmers and also the probit model for awareness points out that receiving farming information through other farmers effectively contributes to an enhanced awareness of climbing beans. Also membership of a farmers' group significantly contributes to the probability of testing climbing beans. This is also shown by descriptive statistics as most farmers (64%) obtained their first seed from climbing beans through other farmers. In a previous small-scale study (60 farmers) by J.J. Ouma (unpublished), similar results were found for farmer-to-farmer transmission of information and seed. Also several other adoption studies in soybean and maize found that membership of farmers' associations positively influenced adoption of improved varieties (Ojiako et al., 2007; Chianu et al., 2007). Hence, it can be concluded that farmer-to-farmer transmission is important in both creating awareness of climbing beans and in testing the climbers. Therefore, a promotion campaign of climbing beans through farmers' groups might succeed although it has to be taken into account that only a minority of farmers would be reached (only 25% is member of a farmers' group). However, it could be argued that by further farmer-to-farmer transmission, awareness would be created beyond farmers' groups and climbing bean seed would be further dispersed beyond members of farmers' groups.

Another variable that appears to be important both at awareness- and trial level is the age of the household head. Older households have higher probabilities on knowing climbing beans and on testing them (Grisley and Shamambo, 1993; Godoy et al., 1998; Agwu et al., 2008). In both cases, a more elaborate social network and a broader farmer experience possibly leading to differences in attitude towards risk, could explain this tendency. Also wealth of the household measured as the number of non-motorized vehicles and motorized vehicles owned, plays a role in awareness as well as trial of climbing beans (Godoy et al., 2008). First, the wealthiest households are less aware of climbing beans probably because their need for improving livelihoods is not particularly important. Secondly, testing climbing beans might be more difficult for the poorest households in the central Kenyan highlands. Possible reasons could be that the poor are particularly dependent on seed purchases and additionally cannot afford to buy seed (David and Sperling, 1999; Almekinders et al., 1994). Also in general, poorer households are less keen on taking risks. Therefore, making climbing bean seed available also to the poorest households might be important in future climbing bean promotion campaigns.

A first variable which exclusively plays a role in the decision to adopt climbing beans is the amount of livestock. In the central Kenyan highlands, zero-grazing dairy farming is an important land use, especially in the higher, cooler and humid areas. As the wealthy biomass of climbing beans can be used as fodder for animals, it would be expected that having many animals would be an incentive to continue growing climbing beans. However, the opposite result was obtained which indicates that livestock tends to act more as a competitor instead of an ally. Probably, competition arises due to limited labour and land availability. When looking at use of the climbing beans by farmers, it appears that use as fodder is only of minor importance. Future promotion campaigns should therefore stress the use of climbing beans as healthy and diversified fodder for animals.

A second variable with an exclusive role in the adoption of climbing beans is land size. As explained in the introduction, climbing beans are often represented as the solution to decreasing land sizes as the same yield can be obtained on a smaller piece of land compared to bush beans. Therefore, the expected result would be that smaller land sizes favour the adoption of climbing beans. Surprisingly however, in this study, land size positively influences the decision to adopt climbing beans meaning that larger land sizes favour adoption. When farmers adopt climbing beans, they actually add this crop to their existing farming system. So often climbing beans are not substituting another crop or part of bush bean cultivation and so this 'extra' crop demands more land. Therefore, researchers and extensionists should realize that small land sizes can actually be a limiting factor for adoption rather than a stimulating one. The addition of novel climbing bean varieties to the agricultural system can actually be considered as advantageous as it brings more biodiversity into the existing farming system and lowers the risk of harvest failure. A serious limitation, possibly the most important for attaining widespread trial and adoption of climbers as indicated by the farmers themselves, is the poor availability of seed. Many aware farmer-households want to test climbing beans but lack the access to seed (42%) and many trial households stopped growing climbing beans because they ran out of seed (39%) and were not able to find it anymore at local markets. Farmers in the central Kenyan highlands obtain seed for planting from their own produce of previous season (42%) or by buying seed at the local market (53%). However, at these markets, climbing bean seed is not available. Farmers who grow climbing beans in the region use it mainly for home consumption and very few of them have ever sold the seed. These results indicate that the missing link in climbing bean trial and adoption is the availability of climbing bean seed at local markets. This problem seems to be specific for Africa (Grisley, 1990; David et al., 2002) and is often an ignored factor in crop varietal adoption studies (David et al., 2002). The few farmers who ever sold climbing bean seed, claim that marketability and prices for the seed are high, especially for the MAC-lines as they represent the locally preferred grain type very well. As a consequence, there is high potential for selling climbing bean seeds at markets. In this sense, the official release of the MAC-varieties by the Kenyan Government in 2008 could be very important as now, the possibility arises to collaborate with seed companies who can produce and sell certified climbing bean seed at large scale. However, it has to be taken into account that very few farmers (0.5%) buy certified seed. This finding is in concordance with previous studies pointing out that the share of the formal seed sector in the total seed supply rarely exceeds 10% in most staple crops in several African and Latin-American countries (Almekinders et al., 1994; David and Sperling, 1999; David, 2004). Main reasons are (i) very high market prices for certified seed; (ii) competition from farmer-saved seed, (iii) strong, region-specific varietal preferences and (iv) low adaptation of certified seed to regional biotic and abiotic stresses (Almekinders et al., 1994; David, 2004). This is why there are no private seed companies who want to produce and market climbing bean seed at large scale (KARI Embu, personal communication). Therefore, an alternative approach could be the set-up of so-called farmer-seed enterprises including local production, selection and selling of seed of improved varieties by farmers themselves. This approach makes use of the existing informal local seed systems in which farmer-to-farmer transmission of farming knowledge and seed is crucial and most farmers (53%) buy seed for planting at local markets. Additional advantages of this approach are: (i) also the poorest households will have better access to seed of improved varieties as it will be cheaper than certified seed, (ii) seed is locally produced and selected making it highly adapted to both local agro-ecological conditions and market preferences, (iii) seed quality and cleanness is equally good as certified seed as proven by various comparative studies (Janssen et al., 1992), (iv) it is sustainable as it is market-driven and demand for climbing bean seed is high in the region, (v) a greater varietal diversity can be offered to farmers, promoting enhanced genetic diversity in the region and (vi) there is a possibility to establish linkages to formal institutions including extension services and commercial seed companies. When setting up farmer-seed enterprises, the main challenge that has to be carefully considered is a proper selection of farmers' groups including farmers who preferably have business experience or who have the reputation to be reliable seed suppliers in the local community. Selected farmers should be trained and supported in the beginning without creating a dependency mentality. Together with seed distribution, these farmers should also provide information and technical assistance to other farmers on climbing bean management. A nice description on the establishment of farmer-seed enterprises in rural Uganda is provided by David (2004).

An interesting opportunity in order to increase awareness of climbing beans could be the use of the radio. According to the results of this study, about 70% of the farmers retrieve farming information through the radio. However, there was no significant effect on awareness nor on climbing bean trial possibly because climbing beans were never promoted through the radio. Promotion of climbing beans through the radio is relatively easy and would reach many farmers. This would have an immediate effect on increasing awareness of climbing beans. Additionally, if appropriate information on how to obtain seed and how to grow climbing beans is included, there could also be an effect on trial and even on adoption of this crop. Agwu et al. (2008) report that radio farmer programmes actually enhanced the extent of adoption of agricultural technologies in Nigeria mainly through the spreading of information. This study also gives some recommendations to maximize the positive effect of a radio programme on agricultural technology adoption.

It is claimed that one of the largest advantages of climbing beans is their high yield potential. In this study, for October rains, the median of yields for climbing beans according to farmers was 1333 kg/ha. This figure is not even close to scientific reports of 4 to 5 tons/ha (which is under optimal conditions with use of fertilizers and pesticides), but is still considerably higher than reported yields for bush beans in farmers' fields in the region (averages of 300 to 800 kg/ha depending on variety, management, zone and weather condition). Also, in this study, adopters indicate high yields of climbing beans as their main advantage. Therefore, when promoting climbing beans, the argument of higher yields can certainly be used but it is advisable to use the actual figures obtained in farmers' fields, not the ones obtained under optimal conditions in experimental fields as this would only deceive farmers when they would test or adopt climbing beans.

Management of climbing beans by trial and adopter households was also verified in this study. All farmers staked the climbing beans at an appropriate time (that is, within the first four weeks after planting). However, about 1/5 of the farmers used stakes that were actually far too short (shorter than 1.50 m). Proper staking is an important requirement for good production of climbing beans. However, it might not be easy for farmers to find sufficient appropriate stakes and to fix these long stakes in the soil. Future promotional activities should again stress the importance of using sufficiently long stakes.

In contrast to other countries such as Rwanda where planting mixtures of up to 30 varieties is very common (Sperling and Muyaneza, 1995), the majority of farmers in the central Kenyan highlands choose to plant few varieties (maximum 3) and pure stands of bush beans. Additionally, since the introduction of the bush GLP-lines by the Kenyan Grain Legume Project in the 80's, no new bean varieties have been introduced. This exceptionally low diversity in bean varieties reflects a very vulnerable system with little adaptability and at high risk if the region would be challenged by severe biotic or abiotic stresses.

In Rwanda, increased incidence of root rot (*Fusarium oxysporum*) and fear of reduced genetic variability on-farm have resulted in the release of many new cultivars simultaneously by the agricultural research institute (ISAR) in Rwanda (Sperling and Muyaneza, 1995). In this sense, introduction of new climbing bean varieties is the first step toward a broadening of genetic diversity. It would also be worthwhile to select more MAC lines in order to improve genetic diversity in climbing beans and beans in general in farmers' fields of the central Kenyan highlands.

## Conclusion

In conclusion, in the central Kenyan highlands, the current situation is one in which many farmers are aware of climbing beans (90%), about 39% of the farmers have tested climbing beans on their farms at least for one season and about 11% of all farmers have adopted climbing beans. Since 2004, trial and adoption rates show a steep increase.

Awareness and trial of climbing beans are significantly higher at higher altitudes. Climbing beans are grown on relatively small areas. From this study, some recommendations can be made on how to improve awareness, trial and most importantly, adoption of climbing beans:

1. As climbing beans seem to be more successful at higher altitudes, promotional strategies should first be focused there.
2. The official release of the MAC-varieties provides the logical step of collaboration with seed companies for certified seed production. However, the establishment of farmer-seed enterprises might have higher local impacts as the existing informal, local seed system would be used to provide farmers with improved climbing bean seed. Careful selection of existing farmers' groups to set up these kinds of enterprises is key in order to obtain success.
3. It could be worthwhile to select more MAC lines in order to improve genetic diversity in climbing beans and beans in general in the central Kenyan highlands. This can also be done by participatory selection of MAC-lines through the farmer-seed enterprises.
4. Future promotion campaigns should stress: (i) the use of climbing beans as healthy and diversified fodder for animals and (ii) the importance of using sufficiently long stakes. In particular this information should be provided to farmers together with seed distribution through farmer-seed enterprises.
5. An interesting opportunity in order to increase awareness of climbing beans could be the spreading of appropriate information on climbing beans and their advantages, on how to obtain seed and how to grow climbing beans through a radio programme.

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