Climbing bean as a solution to increase productivity in land-constrained environments: Evidence from Rwanda

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Abstract

Climbing bean is a potential solution to increase the agricultural sector productivity and sustainability. Using nationally representative bean-producing household data collected in Rwanda, this study identifies factors that influence the decision to switch from cultivating bush to climbing bean and quantifies the impact of climbing bean adoption on yield. About 50% of bean-producing households grow climbing bean; a substantially increased over the past 15 years. Elevation, population pressure, and drought shocks are important drivers of climbing bean adoption. Adoption of climbing bean increases yield by 23% among adopters and has the potential to increase yield by 48% for non-adopters. Findings from this study provide important information for the development of agricultural policies and programs in Rwanda and elsewhere.

Keywords**:** Climbing bean, technological adoption, yield, endogenous switching regression, Rwanda.

Introduction

Sub-Saharan Africa (SSA) urgently needs improvements in agricultural productivity, as landholdings shrink due to population growth. This is particularly true for Rwanda where agriculture is the primary source of livelihoods, malnutrition and poverty remain high, and population continues to grow rapidly. Bean *(Phaseolus vulgaris* L.) is produced by most rural households and is the main source of protein and the second most important source of calories. Annual per capita bean consumption in Rwanda is about 40 kg (Kalyebara and Buruchara, 2008). In the mid-1980s, bean productivity declined due to cultivation expansion into marginal areas and a slow dissemination of new varieties, leading to bean production deficits and concerns about national food security (Graf et al., 1991). This prompted researchers at the International Center for Tropical Agriculture (CIAT) and Rwanda Agriculture Board (RAB) to intensify research on climbing bean. Climbing bean has the potential to produce 3.5 to 5 tons per hectare compared to about 2 tons per hectare for bush bean varieties. In addition, climbing bean creates favorable micro-niches, which reduce fungal pathogen development that negatively affect bush bean productivity (Musoni et al., 2001), and has greater nitrogen fixation capacity than bush bean (Beebe et al., 2012). Over 90 improved bean varieties have been released in Rwanda since the mid-1980s; two-thirds of which are semi-climbers or climbers (PABRA database[1]).

Despite this substantial investment, evidence on adoption of climbing bean varieties is scanty and rigorous assessment of its impact on farm yield is lacking. Most adoption and impact studies were conducted decades ago, rely on experimental data---thus not reflecting the conditions under which farmers operate--, focus on the distinction between improved and local varieties as opposed to bush and climbing, or fail to control for the endogeneity of adoption (Johnson et al., 2003; Kalyebara and Buruchara, 2008; Larochelle et al., 2015; Sperling and Muyaneza, 1995). Sperling and Muyaneza (1995) reported that over 40% of bean-producing households in Rwanda cultivated improved climbing bean varieties, which occupied between 10% to 20% of bean land area in 1993. Johnson et al. (2003) estimated that CIAT-related bean varieties cover 16% of the land area planted to bean in Rwanda. They assessed the yield gain of these improved varieties, through experimental data, at about 900 kg/ha, which was partially attributable to a shift from bush to climbing bean. Based on a survey of 383 households conducted in 2004, Kalyebara and Buruchara (2008) estimated a yield gain of 10-30% for improved varieties over local ones. Using a nationally representative sample of bean producers and an instrumental variable (IV) approach, Larochelle et al. (2015) estimated the yield of improved bean varieties to be on average 62% higher than the yield of local varieties. The authors also found that yield is about 30% higher for climbing than bush bean but they did not address the potential endogeneity of climbing bean adoption.

Climbing bean has greater fertilization requirements and needs staking and as a result are more complex to manage than bush bean (Graf et al., 1991). Farmers with greater abilities may be more likely to overcome these difficulties and adopt climbing bean. Also, the decision to allocate land to bush or climbing bean may depend on soil erosion, exposure to floods, or soil pathogens. If unobservable farmer or plot characteristics are correlated with adoption and yield, then ordinary least squares estimates would be biased.

The objectives of this study are to i) estimating the uptake of climbing bean varieties in Rwanda, ii) identifying factors that influence adoption, and iii) estimating the impact of adoption on yield. Our study contributes to the knowledge of climbing bean in Rwanda in three ways. First, it updates existing information about the adoption rate of climbing bean varieties using a nationally representative household survey of bean producers. Second, it identifies factors affecting climbing bean adoption using an econometric approach which none of the previous studies did. Third, we use an endogenous switching regression (ESR) to control for adoption being endogenous and provide rigorous evidence of the yield difference between bush and climbing bean. Yield is estimated at the plot-level, which enables us to include, in addition to village- and household-level characteristics, plot-specific characteristics, improving the precision of the estimates. Information on factors that facilitate and constrain adoption of climbing bean and its impacts are required to inform future efforts in SSA that aim at promoting adoption of climbing bean as a mean to address land scarcity and increase productivity.

Data and Methods

Data

Analyses in this study are based on a nationally representative household survey conducted from March to August 2011 by RAB in collaboration with CIAT, Virginia Tech, and the International Potato Center. A multi-stage sampling procedure was employed to select villages and respondents. The first stage consisted of stratifying the sample based on the country's ten agro-ecological zones. In the second stage, eighty villages were selected based on weighted probabilities[2]. In the final step, 18 households were randomly selected from each village, giving a total sample size of 1440 households. Approximately 90% of surveyed households grew bean in the studied season, leading to a sample of 1,268 bean-producing households for this study. The household survey gathered information about household and plot characteristics, input usage, harvest, and more. Through community interviews, information that could explain bean varietal adoption independently of its effect on yield was elicited.

Econometric approach

We assume that the decision to grow climbing bean is based on expected utility maximization principle where T^*_{1ij} denotes the expected utility derived from the cultivation of climbing bean on plot *j* by farmer *i* while T^*_{0ij} is the expected utility associated with growing bush bean. Although expected utilities are not observed, we observe the cultivated bean type, which based on the random utility theory can be represented by a binary indicator T_{ij}. If the difference between the two expected utilities, $T^*_{ij} = T^*_{1ij} - T^*_{0ij}$, is greater than zero then climbing bean is adopted and T_{ij}=1. If $T^*_{ij} \leq 0$, then $T_{ij}=0$ indicating non-adoption, i.e. farmer *i* cultivates bush bean on plot *j*. This adoption decision can be represented as:

$$T^*_{ij} = \gamma Z_{ij} + \mu_{ij} \text{ with } T_{ij} = \begin{Bmatrix} 1 \; if \; T^*_{ij} > 0 \\ 0 \; otherwise \end{Bmatrix} \quad (1)$$

Z_{ij} is a vector of exogenous variables, γ is a vector of coefficients to be estimated, and μ_{ij} is a random error term assumed to have zero mean and constant variance.

Given that the decision to adopt climbing bean may be endogenous, we employ an ESR correctly identify the effect of adoption on yield. An ESR makes use of IVs but relaxes the assumption that adoption results in an intercept shift only. We believe that the ESR is more relevant than the traditional IV approach for estimating the impact of climbing bean adoption given its complexity, and the likely different yield responses to input use between the two bean types. An ERS is a two-stage approach; adoption is estimated in the first stage, which is referred to as the selection equation (i.e. equation 1). Conditional on the adoption decision being observed in the first stage, yield is estimated in the second stage as two separate regimes:

Regime 1: $Y_{1ij} = \beta_1 X_{1ij} + \epsilon_{1ij}$ if $T_{ij}=1$ (2.a)

Regime 2: $Y_{2ij} = \beta_2 X_{2ij} + \epsilon_{2ij}$ if $T_{ij}=0$ (2.b)

Y_{1ij} and Y_{2ij} define yield on plot *j* for farmer *i* in the adopting and non-adopting regimes. X_{1ij} and X_{2ij} are vectors of variables explaining yield. Betas are vectors of coefficients to be estimated specific to the climbing and bush bean regimes. $\epsilon_{1ij}$and ϵ_{2ij} are the respective error terms. For the ESR to be identified, Z_{ij} must include all the variables included in the X vectors plus at least one valid IV. A valid IV is one that is correlated with adoption but otherwise not correlated with yield.

Error terms μ_{ij}, $\epsilon_{1ij}$and ϵ_{2ij} are assumed to have trivariate normal distribution with zero mean and the following covariance matrix:

$$\Omega = \begin{bmatrix} \sigma_\mu^2 & \sigma_{1\mu} & \sigma_{2\mu} \\ \sigma_{1\mu} & \sigma_1^2 & \bullet \\ \sigma_{2\mu} & \bullet & \sigma_2^2 \end{bmatrix} \qquad (3)$$

Where σ_μ^2 is the variance of the error term in the adoption equation (1) and is assumed to be equal to 1; σ_1^2 and $\sigma_2^2$are the variances of the error terms in the climbing (2a) and bush (2b) outcome equations; and $\sigma_{1\mu}$ ($\sigma_{2\mu}$) represents the covariance of the error terms between the selection equation μ_{ij} and climbing (bush) bean outcome equation ϵ_{1ij} (ϵ_{2ij}). The dots (•) signify unidentified covariance between $\epsilon_{1ij}$and ϵ_{2ij} given that Y_{1ij} and Y_{2ij} are in two separate regimes and never observed simultaneously. When the error terms of the adoption equation are correlated with those of the outcome equations, the expected values of ϵ_{1ij} and ϵ_{2ij} are non-zero and computed as follow:

$$E\left(\varepsilon_{1ij}\middle|T_{ij}=1\right)=\sigma_{1\mu}\frac{\phi(Z_{ij}\gamma)}{\Phi(Z_{ij}\gamma)}=\sigma_{1\mu}\lambda_{1ij} \quad (4.a)$$

$$E\left(\varepsilon_{2ij}\middle|T_{ij}=0\right)=-\sigma_{2\mu}\frac{\phi(Z_{ij}\gamma)}{1-\Phi(Z_{ij}\gamma)}=\sigma_{2\mu}\lambda_{2ij} \quad (4.b)$$

Where $\phi(\bullet)$is the standard normal probability density function, and $\Phi(\bullet)$, the standard normal cumulative density function. $\lambda_{1ij}=\frac{\phi(Z_{ij}\gamma)}{\Phi(Z_{ij}\gamma)}$ and $\lambda_{2ij}=\frac{\phi(Z_{ij}\gamma)}{1-\Phi(Z_{ij}\gamma)}$ are the inverse mills ratios computed from the first stage and added in the second stage equations to control for the endogeneity of adoption. When the estimated $\hat{\sigma}_{1\mu}$ and $\hat{\sigma}_{2\mu}$are statistically significant, the error terms between the selection equation and outcome equations are correlated and the null hypothesis that adoption is exogenous is rejected (Lokshin and Sajaia, 2004).

The average treatment effect on the treated (ATT) and untreated (ATU) is estimated by comparing expected yield under the actual and counterfactual scenarios for adopters (i.e. climbing bean plots) and non-adopters (i.e. bush bean plots) like in Amare et al. (2012); Di Falco et al. (2011); Asfaw et al. (2012); Kabunga et al. (2012); Kassie et al. (2008); Kleemann et al. (2014); Shiferaw et al. (2014). The formulations for the ATT and ATU are represented by equations 5.a-d (table 1).

Table 1: Conditional expectations and treatment effects for adopters and non-adopters

Sub-samples	***Adopters (Climbing bean plots)***	***Non-adopters (Bush bean plots)***	***Treatment effect***
Climbing bean plots	*5.a)* $E(Y_{1ij}\mid T_{ij}=1)=\beta_1 X_{1ij}+\sigma_{1\mu}\lambda_{1ij}$	*5.c)* $E(Y_{2ij}\mid T_{ij}=1)=\beta_2 X_{1ij}+\sigma_{2\mu}\lambda_{1ij}$	*5.a) –5.c) =ATT*
Bush bean plots	*5.d)* $E(Y_{1ij}\mid T_{ij}=0)=\beta_1 X_{2ij}+\sigma_{1\mu}\lambda_{2ij}$	*5.b)* $E(Y_{2ij}\mid T_{ij}=0)=\beta_2 X_{2ij}+\sigma_{2\mu}\lambda_{2ij}$	*5.d)- 5.b) =ATU*
Heterogeneity effect	*5.a-5.d =* BH_1	*5.c-5.b=* BH_2	*ATT-ATU =TH*

Equations 5.a and 5.b represent the expected yield under the actual scenarios and equations 5.c and 5.d are those of the expected yield under the counterfactual scenarios, i.e. assuming climbing (bush) bean plots were to be planted with bush (climbing) bean. The ATT_{ij} is the yield

gain associated with cultivating climbing bean, and computed as the difference between equation 5.a and 5.c, leading to the following equation:

$$ATT_{ij} = E\left(Y_{1ij}\middle|T_{ij} = 1\right) - E(\left(Y_{2ij}\middle|T_{ij} = 1\right) = X_{1ij}(\beta_1 - \beta_2) + (\sigma_{1\mu} - \sigma_{2\mu})\lambda_{1ij} \qquad (6.a)$$

Similarly, the ATU_{ij} is the yield gain on plot *j* bush bean grower *i* would obtain if she were to plant climbing bean, and is calculated by subtracting equation 5.d from 5.b, leading to the following equation:

$$ATU_{ij} = E\left(Y_{1ij}\middle|T_{ij} = 0\right) - E(\left(Y_{2ij}\middle|T_{ij} = 0\right) = X_{2ij}(\beta_1 - \beta_2) + (\sigma_{1\mu} - \sigma_{2\mu})\lambda_{2ij} \qquad (6.b)$$

We calculate the transitional heterogeneity (TH), which is the difference between ATT and ATU, to determine whether non-adopters would obtain higher or lower yield than adopters if they were to switch to climbing bean. We also calculate the base heterogeneity (BH) for adopters and non-adopters, which measures the possibility that yield could still differ whether plots are planted to climbing or bush bean due to unobservable farmer or plot characteristics. For climbing bean plots (i.e. adopters), the BH_1 is the difference between equations 5.a and 5.d while for non-adopters, the BH_2 is the difference between equations 5.b and 5.c.

Choice of explanatory variables

To explain yield variability between plots, we include indicator variables related to inputs used, plot characteristics and household characteristics. Inputs considered are labor, organic (manure and compost)[3] fertilizers, chemical pesticide, seed, and improved varieties. Since chemical fertilizer and pesticide application is uncommon in the production of both bean types, these inputs enter the equations as dummy variables. Plot characteristics include soil fertility, soil pH, elevation, average monthly rainfall, distance between plot and residence, type of cropping system, and bean varietal diversity. Household characteristics consist of the age, gender and education of the household head and access to agriculture extension service proxied by the distance from the village center to the nearest extension office and captures the ease of obtaining information about the technology.

Since the use of improved varieties is potentially endogenous, a control function approach (CFA) (Smith and Blundell, 1986) is used to test and control for the possible endogeneity of improved varieties, measured as the percentage of planted seed in the plot that is improved. The CFA entails estimating in the first stage a reduced form Tobit model explaining the adoption of improved varieties as a function of all exogenous variables in the production function and a set of IVs[4]. The generalized residuals from the first stage are then included as an additional regressor in the yield equations. Statistical significance of the coefficients for the generalized residuals provides evidence of endogeneity of improved varieties.

We include as IVs in the first stage regression previous occurrence of droughts that caused bean production losses, and population density. Since climbing bean require a reliable level of soil moisture (Musoni et al., 2001), they are less likely to be adopted in areas vulnerable to such abiotic stress. We use village-level occurrence of droughts in the five years prior to the survey as a measure of drought vulnerability to avoid possible correlation with yield in the period studied. High population density results in land shortage, which might favor adoption of labor- and capital-using technologies, such as climbing bean, and could also reduce transaction costs associated with accessing information about the technology and the technology itself.

Results

Descriptive analysis

Overall, 43% of households grow only climbing bean, 49% cultivate only bush bean, and 8% cultivate both bush and climbing bean. At the plot-level, about 48% of the bean plots in Rwanda are planted to climbing bean while about 42% of the bean land area is allocated to climbing bean. Means of variables entering the ESR are presented in table 2, by bean types, and for all plots.

Table 2: Descriptive statistics for variables included in the ESR, by bean types, Rwanda, 2011

	Climbing bean plots		**Bush bean plots**		**All bean plots**	
	Mean	SD	Mean	SD	Mean	SD
Yield (kg/ha) ***	1323.42	1547.57	1095.81	1230.15	1205.61	1396.61
Labor (Man-days/ha) ***	502.56	566.71	363.47	521.42	429.96	547.83
Organic fertilizer (kg/ha) ***	8080.2	18858.8	5190.63	15218.9	6584.51	17128.39
Chemical fertilizer (1=yes) ***	0.14	0.34	0.05	0.22	0.09	0.29
Pesticide application (1=yes)	0.02	0.13	0.01	0.09	0.01	0.11
Proportion of improved seed ***	0.17	0.36	0.32	0.45	0.25	0.42
Soil fertility (1= good)	0.39	0.49	0.41	0.49	0.4	0.49
Seeding rate						
< 60kg/ha***	0.26	0.44	0.32	0.47	0.29	0.46
60 - 80kg/ha***	0.49	0.50	0.37	0.48	0.43	0.49
> 80kg/ha***	0.25	0.43	0.31	0.46	0.28	0.45
Extension in the village	0.36	0.48	0.46	0.50	0.41	0.49
Yes ***						
Within 2 hours walk***	0.14	0.35	0.11	0.32	0.13	0.33
> 2 hours walk**	0.49	0.50	0.42	0.49	0.46	0.50
Soil pH (ideal=1) ***	0.24	0.42	0.18	0.38	0.21	0.4
Elevation (m) ***	1846.39	249.87	1543.06	211.62	1689.38	276.14
Monthly average rainfall (2004-8) ***	16.02	0.6	15.86	0.8	15.94	0.71
Distance home to plot (min. walk)	17.29	28.51	16.8	21.75	17.04	25.24
No. of varieties per plot						
1 variety***	0.88	0.33	0.81	0.39	0.85	0.36
2 varieties***	0.09	0.29	0.13	0.34	0.11	0.31
3&+ varieties***	0.03	0.17	0.06	0.23	0.04	0.2
Plot intercropped (1=yes) ***	0.28	0.45	0.65	0.48	0.47	0.5
Age of HH head	45.36	13.72	44.16	13.16	44.74	13.44
Gender of HH head (1=male)	0.78	0.42	0.74	0.44	0.76	0.43
HH head education						
No education	0.24	0.43	0.29	0.45	0.26	0.44
Primary education	0.71	0.45	0.67	0.47	0.69	0.46
Secondary education	0.05	0.21	0.04	0.2	0.05	0.21
Population density (ind./0.8km^2) ***	303.31	120.20	238.12	102.69	269.50	116.10
Drought in the past 5 years (1=yes) ***	0.39	0.49	0.82	0.38	0.61	0.49
Number of Observations (%)	944 (48)		1017 (52)		1961 (100)	

Note: ***, **, * denotes that averages between climbing and bush bean plots are statistically different at 1, 5, and 10% level; HH=Households; SD.=Standard Deviation.

On average, yield is statistically greater for climbing than bush bean. Labor devoted to bean cultivation, mainly provided by family members, is statistically higher for climbing than bush bean. Organic fertilizer applications average 8,080 kg/ha for climbing bean compared to

5,190 kg/ha for bush bean. Chemical fertilizer was applied to 14% of climbing bean plots and only 5% of bush bean plots. About one percent of bean plots received pesticide application. Most farmers do not follow the recommended seeding rate of 60-80 kg/ha; it exceeds 80 kg/ha on 25% and 31% of climbing and bush bean plots and is below 60 kg/ha on 26% and 32% of plots climbing and bush bean plots. About 25% of planted seeds are improved varieties and this proportion is significantly higher for bush bean plots. Last, climbing bean growers reside in areas with greater population density and where occurrences of drought are less likely.

Econometric Analysis

In this subsection, we first present the results of the diagnostic tests for the IVs and model specification. Then, we discuss the determinants of climbing bean adoption, factors influencing yield, and adoption impact on yield.

Several tests were conducted to assess the validity of the IVs. The Hansen J statistic, a test for over-identification of all instruments, indicates that the instruments are valid as the null hypothesis is not rejected (p-value =0.338). The Kleibergen-Paap rk LM statistic and Kleibergen-Paap rk Wald F statistic were computed to test for underidentification and weak identification. The null hypothesis is rejected at 1% level for each test, suggesting that the model is well-identified and weak-inference bias should not be an issue[5]. A falsification test conducted following Di Falco et al. (2011) indicated that the IVs have no effect on bush bean yield[6]. Last, the Wald test for the joint independence of the three equations (second to the last row of table 3), which test that $\hat{\sigma}_{1\mu} = \hat{\sigma}_{2\mu} = 0$, could not be rejected, suggesting no selectivity bias. Despite this finding, we keep the ESR specification since we rejected the null hypothesis that climbing bean adoption is exogenous based on a Hausman test and obtained different coefficients in the yield equations between bush and climbing bean plots, indicating the presence of heterogeneity in the sample (Di Falco et al., 2011). We assess the robustness of the

ESR results using a sub-sample of households growing both bush and climbing bean, and present findings at the end of this subsection.

Determinants of adoption

As indicated above, the two IVs are significant in explaining the decision to grow climbing bean. A ten-unit increase in population density increases the probability that a plot will be allocated to climbing bean by one percentage point (table 3, columns 1 & 2). Village-level occurrence of droughts in the past five years prior to the survey reduces the likelihood of adopting climbing bean by 16 percentage points. Besides the IVs, the most important variable associated with the adoption of climbing bean is elevation. Soil fertility and pH are also important determinants of climbing bean adoption. Compared with bush bean, climbing bean more likely to be planted on plots with low and medium soil fertility but soil pH within the recommended range. In addition, climbing bean plots are less frequently intercropped, planted with improved varieties, and cultivated with three or more varieties simultaneously. The distance between the plot and homestead significantly reduces the probability of a plot being allocated to climbing bean cultivation.

Determinants of yield

Most inputs have a positive and significant impact on yield. However, the yield response to input use differs between bush and climbing bean cultivation for few inputs. A one-percent increase in organic fertilizer application leads to a yield gain of 0.13% for climbing bean compared to 0.07% for bush bean (table 3, columns 3-6). Chemical fertilizer and pesticide application increase climbing bean yield by 18% and 41%, but these variables are insignificant in the bush bean outcome equation. Growing improved varieties is associated with a yield gain of 39% for climbing bean and 32% for bush bean. Bean seeding rate has a significant effect on bush and climbing bean yield. The average yield gain associated with using the recommended seeding levels is about 60% and higher for seeding rates above 80 kg/ha compared to seeding rates below 60 kg/ha.

Table 3: ESR results for climbing bean adoption and its impact on yield, Rwanda, 2011.

Variables	**Selection Eq.**		**Impact on yield**			
	Adoption		Climbing bean		Bush bean	
	M.E.	S.E.	Coef.	S.E.	Coef.	S.E.
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Proportion of improved seed	-0.37***	0.07	0.39*	0.21	0.32*	0.18
Generalized residual improved seed	0.93***	0.25	-0.93	0.74	-0.93	0.66
Pesticide application (1=yes)	-0.08	0.1	0.41***	0.16	0.47	0.29
Organic fertilizer (kg/ha)	0.02*	0.01	0.13***	0.03	0.07***	0.03
Labor (man-days/ha)	0.03**	0.01	0.54***	0.03	0.58***	0.03
Intercropped (1=yes)	-0.09***	0.02	0.19**	0.1	0.06	0.06
Chemical fertilizer application (1=yes)	0.001	0.03	0.18**	0.08	-0.25	0.18
Soil fertility (1= good)	-0.05***	0.02	0.12*	0.06	0.13***	0.05
Bean varietal diversity (Base = 1 variety)						
2 varieties	-0.05	0.03	0.06	0.1	0.27***	0.07
3 or more varieties	-0.10**	0.05	0.33***	0.13	0.28**	0.12
Seeding rate (base= below 60kg/ha)						
60-80kg/ha	0.003	0.03	0.60***	0.09	0.66**	0.09
>80kg/ha	-0.10***	0.03	0.84***	0.09	0.93***	0.08
Dist. from dwelling to plot (min. walk)	-0.03***	0.01	0.0001	0.02	-0.01	0.02
Elevation (m)	0.99***	0.1	-0.91	0.7	-0.41	0.29
Avg. monthly rainfall (2004-8)	0.28	0.32	5.54***	1.05	3.58***	0.78
Education of HH head (Base=none)						
Primary	0.02	0.03	0.12	0.08	0.21***	0.07
Secondary	-0.06	0.05	0.2	0.13	0.07	0.13
Age of HH head	0.01	0.03	-0.004	0.1	-0.20**	0.1
Gender of HH head (1=male)	0.04	0.02	0.02	0.08	0.08	0.06
Soil pH (1=ideal)	0.19***	0.04	0.07	0.11	0.11	0.08
Extension (base= in village)						
within 2 hours walk	-0.01	0.03	-0.15**	0.08	-0.05	0.08
>2 hours walk	0.04	0.05	-0.18	0.12	0.1	0.12
Population density (ind./0.8km^2)	0.001***	0.0001				
Drought at village-level in last 5 years	-0.16***	0.02				
Ln(Sigma)			0.70 ***	0.04	0.71***	0.03
Rho			-0.24	0.33	0.13	0.12
Log pseudolikelihood	-2915.3762					
Wald Test of independence of Eqns.	Chi^2 =	1.6		p-value=	0.2065	
Number of observations	1961		944		1017	

Notes: M.E.=Marginal effects; S.E.=Standard errors clustered at the household-level; ***, **, * denotes that the marginal effects are significant at the 1, 5, and 10% level; HH=Household.

Plot characteristics that significantly influence yield are soil fertility, rainfall, type of cropping system, and varietal diversity (table 3, columns 3-6). Yield is on average 13% (12%) lower for climbing (bush) bean grown on low and medium soil fertility compared with good soil fertility. Rainfall has a strong and positive impact on yield, with the coefficient being of larger magnitude for climbing bean. One percent increase in average monthly rainfall boots yields by 5.5% for climbing bean and 3.6% for bush bean. Climbing bean yield is higher when the plot is intercropped compared with monocropping, perhaps because of the benefits associated with the interaction between crops that abates yield loss due to disease and pest spread. Planting more than one bean variety in the same plot increases yield. Yield responsiveness to household demographics is specific to the bean type. A one-year increase in the age of the household head reduces bush bean yield by 0.2% while bush bean yield is 21% higher among households whose head has primary education compared to those whose head has no formal education.

Adoption impact on yield

The yield advantage of climbing bean over bush bean is one of the factors hypothesized to drive its adoption. The average yield gain associated with switching from bush to climbing bean is estimated for adopters and non-adopters by comparing predicted yield under actual and counterfactual scenarios. The predicted yields under actual scenarios average 1,473 kg/ha for climbing bean plots and 1,367 kg/ha for bush bean plots (table 4, cells a-b). Under the counterfactual scenario, climbing bean adopters would produce on average 1,202 kg/ha had they planted bush bean. This means that adopters obtain an additional 270 kg/ha from climbing bean cultivation compared to the situation where they had not adopted, or a yield gain of 22.5%, which is the ATT. Under the counterfactual scenario, bush bean growers would obtain an average yield of 2,024 kg/ha; this is if they were to switch to climbing bean cultivation. This represents an additional output of 657 kg/ha or a yield gain of 48%, which is the ATU.

Table 4: Average predicted bean yield (kg/ha), and treatment and heterogeneity effects

Sub-samples	***Decision stage***		***Treatment effect***	
	Climbing bean (Kg/ha)	*Bush bean (Kg/ha)*		
Climbing bean	1473.12 (a)	1202.36 (c)	ATT=270.76	22.52%
Bush bean	2024.86 (d)	1367.42 (b)	ATU=657.44	48.08%
Heterogeneity effects	BH_1=-551.72	BH_2= -165.07	TH= -386.68	

The TH is negative implying that on average, the yield gain from adopting climbing bean is higher among farmers who have not yet adopted compared to those who have. The BH is negative under both scenarios. Adopters of climbing bean would obtain lower yield than bush bean growers assuming both were to grow climbing bean, represented by the negative BH_1 of 551 kg/ha, or both were to cultivate bush bean, represented by the BH_2 of -165 kg/ha. This means that there is unobserved heterogeneity that makes climbing bean adopters on average worst off than bush bean producers, such as cultivation on more marginal and degraded land.

Robustness check

To test the robustness of our results, we re-estimate the same yield equation on a subsample of 104 households that grow both bush and climbing bean, which includes 259 plots, using ordinary least squares. Standards errors are clustered at the household-level as previously. The logic behind this approach is that the production environment for bush and climbing bean plots grown by the same household should be very similar and unobserved household characteristics that could positively (or negatively) influence yield should work in the same direction for bush and climbing bean plots. A positive and significant coefficient on the dummy variable for climbing bean provides additional evidence of the superiority of climbing bean in terms of yield over bush bean since the yield gain can be difficulty attributable to differences in agro-climatic conditions or unobserved household heterogeneity[7]. Among households that grow both bean types, yield is 23% higher for plots planted with climbing bean compared with those planted with bush bean. The coefficient is significant at the 5% level and consistent with the results obtained from the ESR[8].

Discussion

Since the 1980s, significant research investment has been devoted to the development and dissemination of climbing bean varieties in Rwanda based on their high yielding potential and hence suitability to intensify bean production in land-constrained environment. Despite this important undertaking, national adoption rate of climbing bean, factors influencing adoption, and yield differential between bush and climbing beans measured under farmer conditions were missing up to this point. This study contributes to the literature by closing these gaps.

Slightly over 50% of bean growers in Rwanda cultivated climbing bean varieties in 2011 but 43% of bean land area was cultivated under climbers. This suggests that climbing beans are more popular in land-constrained environment which is supported by the econometric results; population density has a significant and positive impact on adoption. Consistent with previous finding (Musoni et al., 2001), climbing bean adoption is more likely at higher elevation where households farm on steep slopes, which increases the risk of soil erosion. Given its long production cycle and ability to form a thick canopy, climbing bean cultivation can contribute to environmental conservation in marginal areas by providing protective soil cover which can reduce erosion associated with heavy rainfall. Moreover, the prior information that climbing bean exhibits better resistance to fungal foliar and root disease and have higher potential to recover from heavy rainfalls underscores its potential as strategy for climate change adaptation in the East African highlands. Climbing bean is also cultivated on plots closer to the homestead compared to bush bean which could be due to higher efficiency losses associated with unproductive labor efforts, such as walking to the plot (Larochelle and Alwang, 2013), for climbing than bush bean since climbing bean has a longer vegetative cycle and greater input requirements. Consistent with the findings of Sperling and Muyaneza (1995), our study reveals no influence of household demographics on adoption of climbing bean.

Our study is the first to quantify the impact of climbing bean adoption on yield based on household data. We use a rigorous econometrics approach to control for endogeneity of adoption and allow yield response to inputs use, plot characteristics, and household characteristics to differ between bush and climbing beans, which is an additional contribution of our research. This distinction is important since the significance and magnitude of the impact of these factors on yield vary between the two bean technologies. Adoption of improved varieties increases bush and climbing bean yield, however adoption is lower among climbing bean growers. This calls for interventions to develop seed systems specific to climbing bean to speed up their adoption. The positive impact of pesticide application on climbing bean yield could be a signal of existing environmental stresses, which could be addressed with the development and promotion of new resistant varieties and complementary management practices.

Adoption of climbing bean significantly increases yield in Rwanda, which is of great importance to achieve food security and poverty reduction in a country where small landholdings pose a big challenge. This study reveals an average yield gain of 22% among adopters and a potential yield gain of 48% for non-adopters. Our results confirm earlier findings from on-station experiments of the superior yielding properties of climbing over bush bean. However, the yield impact for adopters is far below the potential yield advantage demonstrated through field experiments. Our study provides few explanations for this yield gap; unobserved heterogeneity that put climbing bean growers at a disadvantage, such as farming on marginal land, and underutilization of inputs, including seeds and fertilizers. In the context of degraded soils, additional efforts should be devoted to interventions that promote effective soil fertility management practices to unleash the yield potential of climbing and bush bean in Rwanda. Options to improve soil fertility include the promotion of chemical fertilizer applications and integrated crop-livestock farming system, especially with climbing bean, which produces significant quantities of biomass to serve as livestock feed. Results indicate that climbing bean is also more responsive to fertilizers relative to bush bean, which makes this integrated agricultural system very attractive for addressing Rwanda agriculture challenges. On the other hand, bush bean growers would obtain higher yield gains from the cultivation of climbing bean, and yet they have not adopted. These farmers may be hesitant to switch to climbing bean due to barriers such as constrained access to planting and staking materials, high opportunity cost of adoption related to learning new crop management practices, and greater input requirements.

Conclusions

Our study revealed that climbing bean varieties are grown by slightly over half of bean producing households in Rwanda and are more likely to be adopted in high elevation and high population density areas and on soil of lower fertility compared to bush bean. Using an ESR, we estimated the yield advantage of climbing bean over bush bean to be 22% for current adopters and 48% for non-adopters. Our results highlight the role climbing bean can play in mitigating land scarcity and support the idea of scaling up the technology to other areas in SSA where high population density causes land fragmentation and diminishing landholdings. While our analysis indicates that climbing bean adoption increases yield, growing climbing bean is also associated with higher input use. This study did not examine the differences in production costs and revenues incurred by farmers growing climbing vs. bush bean, which could possibly be one of the underlying cause for non-adoption. Such analysis would guide future efforts aiming at promoting climbing bean varieties to non-adopters and scaling up the technology outside Rwanda. Nevertheless, we conclude that in the context of severe land pressure and limited off-farm employment opportunities, the utility derived from its higher yield drives the adoption of climbing bean in Rwanda.

Notes

1. Available at http://database.pabra-africa.org/
2. Weighted probabilities were computed when feasible according to averaged land area for the three crops considered in the study, i.e. bean, sweet potato, and potato. Land cultivated by crop was not available at the village-level and thus, village population was used for weighting.
3. Observations with zero value for organic fertilizer application were handled as suggested in Battese (1997) to avoid dropping these observations or creating bias by assuming that log(0)=0.
4. The IVs for the adoption of improved varieties are the presence of market service for crops in the village and village adoption rate of improved varieties in the season preceding the studied season. The validity of these IVs was tested using the Stata command "Ivreg2" (Baum et al., 2007). Kleibergen-Paap rk LM statistic has a p-value =0.001 & Hansen j statistics, a p-value=0.290.
5. Test statistics are heteroskedasticity-robust and performed using the Stata command "Ivreg2" (Baum et al., 2007)
6. P-values for population density and drought occurrence in the previous five years are 0.175 and 0.825.
7. However, one could argue that differences in yield could be due to unobserved plot characteristics.
8. Results from these additional analyses are excluded to keep the length of paper short but can be made available from the authors on request.

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