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Adoption of Improved Groundnut Varieties in Uganda

Bekele Shiferaw , Geoffrey Muricho, Julius Okello, Tewodros A Kebede and Geresom Okecho

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International Crops Research Institute for the Semi-Arid Tropics

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Abstract

This paper evaluates the level of adoption of improved groundnut varieties and the role of information, seed supply and credit constraints for variety adoption in rural Uganda. We use large-scale primary survey data collected in seven groundnut growing districts to understand the adoption behavior of farm households and the key determinants of variety uptake. The study finds that the level of adoption of improved varieties in Uganda is very high; about 59% of the households grow improved varieties. About 62% of the groundnut area is planted to improved varieties, indicating a high intensity of adoption. On average, the income per ha from improved varieties is about 80% higher than local cultivars. Owing to the interdependence of variety choice decisions, we use a multivariate probit specification to identify variety-specific drivers of adoption. About 10% of farmers lack information on new varieties, while 18% and 6% cannot adopt mainly due to seed supply and capital constraints, respectively. This indicates that a tobit-type specification, which considers all non-adopters as disinterested in the technology would lead to inconsistent parameter estimates and misguided conclusions. We therefore estimate a modified multi-hurdle specification, which takes into account the information, seed supply and capital constraints in determining the desired demand and intensity of adoption of new groundnut varieties. These findings provide new insights as to why adoption of new agricultural technologies in Africa has lagged behind – not so much due to lack of economic incentives, but due to the persistent failure to provide vital information along with seeds and required credit to translate the desired positive demand into effective and actual adoption of new varieties. These are important lessons that need to be considered as Africa searches for alternative pathways to launch an effective and sustainable green revolution that will transform smallholder agriculture.

Acknowledgment

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Adoption of Improved Groundnut Varieties in Uganda

1. Introduction

Uganda is one of the major producers of groundnut in eastern and southern Africa. Groundnut is the second most widely grown legume in the country after the common bean. Groundnut production has been gradually growing since 1991. Groundnut provides multiple benefits to smallholder farmers growing the crop. It serves as an inexpensive source of protein to families who cannot afford the more expensive animal-based diets (Rachier 2005). For households who can afford to produce a surplus for markets, it provides scarce cash income that can be used for investing in health, children's education, and other necessities. This makes groundnut an important food security crop in both rural and urban areas of Uganda (Obuo et al. 2004). As a legume crop, groundnut also provides additional benefit for enhancing soil fertility through fixation of atmospheric nitrogen, especially important given the high cost of chemical fertilizers. This contributes to increased land and labor productivity for smallholder producers (Coelli and Fleming 2004). Groundnut is also used as a trap crop in the management of productivity-lowering *Striga* weed on cereals (eg, sorghum and maize), which is a major problem in the groundnut growing regions of eastern Africa. In many communities where the crop is grown, its leaves and haulms make nutritious animal feeds, while the groundnut meal – a byproduct of oil extraction – serves as another important protein supplement for livestock.

Despite the numerous benefits of growing groundnut, its production in Uganda has remained heavily constrained by diseases and pest pressure and frequent droughts. The viral disease, rosette, is one of the most devastating problems that has limited productivity growth. In partnership with ICRISAT, which supplied several disease resistant and high-yielding cultivars, the National Agricultural Research Organization (NARO) of Uganda started a targeted breeding program in the early 1990s to develop new resistant varieties. The research aimed at identifying and selecting locally adapted varieties that are resistant to rosette disease and tolerant to abiotic stress, especially drought. By the end of 2002, a total of five improved varieties most of them resistant to the groundnut rosette disease had been tested and released. Some of these have been promoted widely for adoption.

Although technology adoption is one of the most researched areas in agricultural economics, very few studies (Mohsin and Mirza 2004, Freeman et al. 2001) have looked at adoption of groundnut technologies under smallholder agriculture. Existing studies either assess only the potential for adoption (eg, Freeman et al. 2001) or are based on a small sample of respondents in project areas and cannot be used to understand the determinants of adoption and impacts of groundnut technologies in the wider growing region. In addition, many adoption studies are based on the assumption that smallholder farmers are aware of and knowledgeable about new technologies. Under such conditions, the zero (non-adoption) generating process for both divisible and non-divisible technologies leads to a clear rejection of the new technology by the informed user in the long-term (Dimara and Skuras 2003). Such an adoption response is modeled using probit and logit models for non-divisible technologies or using tobit-type models for divisible technologies.

In reality many farmers in sub-Saharan Africa lack reliable information and knowledge about new technologies and cannot make the adoption choice. A farmer lacking information about the available options misses the opportunity to evaluate the relative performance of alternative technologies under local conditions. Under these conditions, a corner solution, which regards all zero values as informed choices made not to use the technology will be misleading. In addition, when information is available and farmers can make an informed adoption decision, many farmers with a positive desired demand for new technologies may fail to realize this potential demand due to various constraints (Croppenstedt et al. 2003, Shiferaw et al. 2008). This implies that many non-adopting farmers could be adopters of new technologies if the limiting constraints (eg, input supply, credit, etc) were addressed. Under such circumstances, using a model that accounts only for censorship but fails to consider the difference in desired and actual demand for new technologies would lead to inconsistent parameter estimates (Coady 1995, Croppenstedt et al. 2003).

Our study adds value to the existing literature by using a large household survey to examine factors that affect farmers' adoption choices and intensity of adoption of improved rosette resistant varieties (RRVs) conditional on availability of information and other limiting constraints (seed supply and credit). Based on a recent survey of groundnut farmers in Uganda, the study evaluates the spread and intensity of adoption of improved RRVs, and analyzes the determinants of variety uptake and the key policy-relevant constraints faced by smallholder farmers. The multiple thresholds that farmers need to overcome in their technology choice and investment decisions are analyzed using a modified version of the double hurdle model (Cragg 1971, Coady 1995, Croppenstedt et al. 2003), which explicitly takes into account the effect of information and other adoption constraints.

Unlike many previous studies where there was only one improved variety (eg, Nkonya et al. (1997), Zavale et al. (2005), Salasya et al. (2007)), our study also examines cases where farmers make a choice between several improved varieties. We use a multivariate (MV) probit model, which allows estimation of several correlated binary choices jointly (Greene 1997, Chib and Greenberg 1998). The MV probit model takes into account the potential interdependence in technology choice and the possible correlation in the adoption of alternative improved varieties. The probability of adoption of any particular groundnut variety is estimated conditional on the choice of any other related variety.

The rest of the paper is organized as follows. Section 2 provides a conceptual framework for farm household constrained technology adoption under smallholder agriculture. The third section presents the context and analytical methods with emphasis on production systems, data, empirical models and hypothesized relationships. The main analytical results are presented and discussed in Section 4. We conclude in Section 5 by presenting the key findings and the policy implications for stimulating the adoption of groundnut technologies in Uganda.

2. Smallholder technology choice and adoption

Smallholder groundnut farmers in Uganda are simultaneously involved in both production and consumption decisions. As in many developing countries in Africa, smallholder farmers face imperfect input and credit markets. We particularly consider that credit markets for agricultural inputs are imperfect and rationed. Lack of employment opportunities in rural areas for many farm households also implies that labor markets are either missing or highly imperfect. These market failures result from poverty, underdeveloped non-farm sector, asymmetric information and high transaction costs, especially in credit and input markets. In such situations, the relevance of a separable household model where consumption and production decisions are made independently is questionable. The non-separable household model provides a suitable framework for analyzing household micro-economic behavior under market imperfections. This implies that household resource allocation including on-farm technology adoption and off-farm labor supply is determined simultaneously rather than recursively (de Janvry et al. 1991).

The household is assumed to maximize the following utility maximization function subject to income, production technology and time constraints:

1) $Max\, U = U(C_a, C_m, C_l, k, z_h, \varphi)$

Subject to the constraints:

2) $p_m C_m \leq p_q (Q_a - C_a) - p_x x(A) + R$ (income constraint)

3) $Q_a = Q(x(A), L_f(I); k, z_h, z_q, A, \theta)$ (technology constraint)

4) $p_x x_2 \leq E + R$ (credit constrained inputs, $x_2 \in x$)

5) $L_f(A) + C_l \leq T$ (time constraint)

where C_a is demand for produced agricultural staple; C_m is purchased consumption, C_l is leisure (home time); Q_a is production of agricultural staple (so that $Q_a - c_a$ is its marketed surplus); k is household endowments of physical capital; z_h household characteristics; φ other exogenous factors that may affect households preferences such as weather and illness, L_f is family labor used on-farm; R is exogenous income (eg, transfers and remittances); p_m and p_q are the prices of the purchased and produced staple, respectively; A is area grown under new technology; p_x and x are the price and quantity of farm inputs other than labor; $x_2 \in x$ is the set of credit constrained purchased inputs (while x_1 is not constrained); E is credit accessible from different sources; z_q is farm and village level fixed-factors that determine local comparative advantages (eg, access to markets, infrastructure, farming systems); T is total endowment of family labor time, and θ a random factor that shifts the production function.

Groundnut technology adoption (A) may change household resource allocation (eg, fertilizer, labor, land) and thus costs of production. This implies that use of farm inputs will be a function of extent of adoption of the technology (A). We assumed that in the short to medium term technology adoption may not change output and input prices. The Lagrangian associated with the constrained maximization after substituting (3) and (4) into (2) can be given as:

6) $$\lambda = U(c_a, c_m, c_l, k, z_h, \varphi) + \lambda[p_q Q(x_1(A), x_2(A), L_f(A); k, z_h, z_q, A, \varepsilon) - p_x x_1(A) - p_x x_2(A) + R - p_m c_m - p_a c_a] + \rho\left[E - p_x x_2(A) + R\right] + \gamma\left[T - L_f(A) - C_l\right]$$

Assuming interior solutions the first order conditions are derived as follows:

7) $$\frac{\partial \lambda}{\partial A} = \lambda\left[p_q\left(\frac{\partial Q}{\partial x}\frac{dx}{dA} + \frac{\partial Q}{\partial l}\frac{dL}{dA} + \frac{\partial Q}{dA} - p_x \frac{\partial x}{\partial A}\right)\right] - \rho\left(p_x \frac{\partial x_2}{\partial A}\right) - \gamma\left(\frac{\partial L}{\partial A}\right) = 0$$

8) $\frac{\partial \lambda}{\partial x_1} = \lambda \left(p_q \frac{\partial Q}{\partial x_1} - p_x \right) = 0$

9) $\frac{\partial \lambda}{\partial x_2} = \lambda \left(p_q \frac{\partial Q}{\partial x_2} - p_x \right) - \rho(p_x) = 0$

10) $\frac{\partial \lambda}{\partial L} = p_q \left(\frac{\partial Q}{\partial L} \right) = \frac{\gamma}{\lambda} = p_l^*$ (shadow value of family labor)

11) $\frac{\partial \lambda}{\partial c_l} = u_l - \lambda p_l^* = 0$

12) $\frac{\partial \lambda}{\partial c_i} = u_i - \lambda p_i = 0 \quad i \in a, m$

13) $p_q Q(x(A), L_f(A); k, z_h, z_q, A, \theta) + R + E - p_x x(A) - p_m c_m - p_a c_a = 0$

Solving these equations simultaneously the technology adoption decision conditions may be approximated by:

14) $p_q \frac{dQ}{dA} - p_x \frac{\partial x}{\partial A} - \left(\frac{\rho}{\lambda} \right) p_x \frac{\partial x_2}{\partial A} - \left(\frac{\gamma}{\lambda} \right) \frac{\partial L}{\partial A} = 0$

Equation (14) is the marginal benefit-marginal cost condition for adoption. The first term is the marginal change in productivity resulting from adoption. The second term is the change in the marginal cost of production due to adoption. The third term is the additional cost of adoption associated with changes in the level of use of credit constrained purchased inputs (x_2), which will be positive if adoption requires more of these inputs (eg, improved seeds, fertilizer, etc). The last term is the change in demand for labor input, which could be negative if adoption is labor-saving and positive if adoption is labor-intensive. These results indicate that the farmer would adopt the new technology up to the level where the marginal benefit would be equal to the marginal costs. The imperfections in credit and labor markets will have a direct effect on the adoption decision and the intensity of adoption. The third and fourth terms indicate that the marginal cost of adoption would be higher for credit and labor constrained households when adoption requires more of these inputs. This will reduce the net gain from adoption and make the technology less profitable or limit the intensity of adoption. This indicates the importance of considering farm and household characteristics along with institutional factors in understanding the adoption behavior of farm households. These variables will be included in the empirical model developed in the next section.

3. Data and Methods

3.1 Groundnut in Uganda

Uganda is one of the major producers of groundnut in eastern and southern Africa (Figure 1). However, groundnut production in Uganda has remained heavily constrained by diseases, pests and frequent droughts, which have jointly contributed to low farm level productivity of the crop. Some evidence suggests that losses due to pests and diseases generally exceeded those due to soil fertility, drought and poor planting material (Bonabana-Wabbi et al. 2006). Rosette is the most destructive virus disease of groundnut in sub-Saharan Africa. The rosette epidemic in 1994/95 in Malawi and Zambia devastated the crop (eg, crop area in Malawi declined from 92,000 in 1994/95 to 65,000 ha the following year). Overall annual losses in Africa due to rosette were estimated at about US$156 million (ICRISAT 2005). The disease incidence may be minimized by insecticidal control of the vector (aphids) and other agronomic practices, but such practices are either capital or knowledge-intensive and hence seldom adopted by smallholder farmers in Africa. Therefore, host-plant resistance to the disease is regarded as the most viable and sustainable solution.

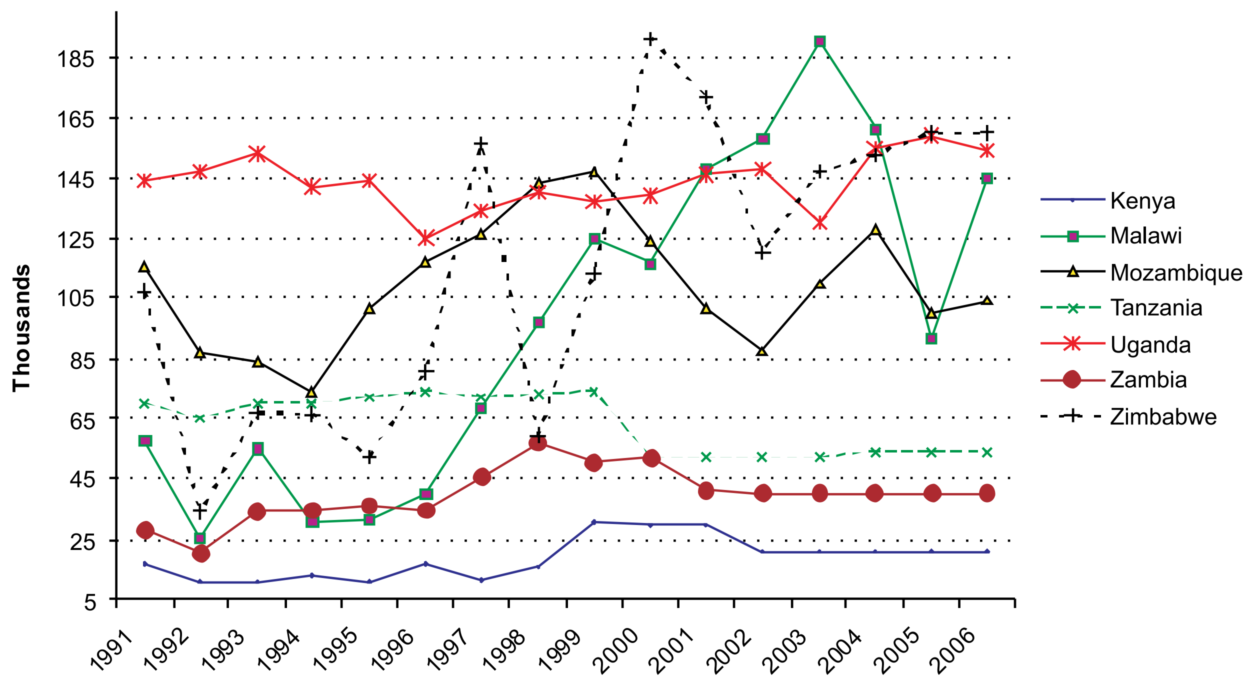

Figure 1: Trends in area under groundnut production in the major producing countries in eastern and southern Africa.

Source: FAOSTAT, accessed 26 November 2007.

In order to address these challenges, the National Agricultural Research Organization (NARO) of Uganda in collaboration with ICRISAT's regional groundnut breeding program in Malawi started a targeted breeding effort in the early 1990s in Uganda. The groundnut screening, evaluation and selection activities were conducted at NARO's Serere Agricultural and Animal Research Institute (SAARI) located near Soroti town. The research aimed at identifying and selecting locally adapted varieties that are resistant to the rosette virus and tolerant to abiotic stress, especially drought.

A total of five (Igola, Serenut 1, Serenut 2, Serenut 3 and Serenut 4) improved groundnut varieties had been released as a result of the research activities at SAARI by the end of 2002. Except Serenut 1, which is a high-yielding but susceptible variety, all the other improved varieties are resistant to the rosette virus hence reducing the overall losses from the rosette disease (Appendix 1). The release of these improved varieties was followed by an aggressive promotion program funded by the government of Uganda and several development partners. The promotion was led by Uganda's National Agricultural Advisory Services (NAADS), a quasi-government organization established in 2001 to develop demand-driven and farmer-led agricultural service and technology delivery systems. Despite these efforts, there is to date no study that has examined the adoption and impact of such varieties. This study aims to bridge this gap by focusing on the determinants of farmer technology uptake and policy-relevant constraints that need to be addressed to facilitate smallholder access and adoption of promising groundnut RRVs in Uganda.

3.2 Sampling procedure

The primary survey was done in two stages. First, a reconnaissance survey was conducted by a team of scientists to have a broader understanding of the groundnut production and marketing conditions in Uganda. During this exploratory survey, discussions were held with farmers, traders and extension staff working directly with farmers. The findings from this stage were used to refine the study objectives, sampling methods and the survey instrument.

The household survey was then carried out in seven districts drawn from five farming systems where groundnut is widely grown (Appendix 2). One district was randomly selected to represent each farming system, except for the banana-cotton-millet system where three districts were randomly sampled owing to the large number of groundnut growing districts (Table 1). A multi-stage stratified sampling technique was used to sample households in each of the selected districts. In each district, a list of all groundnut growing sub-counties was identified and three sub-counties were randomly selected. This was followed by random selection of three parishes from each sub-county, providing 9 parishes per district from which one village was randomly selected. A random sample of 15 households was selected from each village providing a total of 135 households per district, and 945 households in seven sample districts.

Table 1. Farming systems and sampled districts.

Farming system	Districts growing improved varieties	Sampled district
Teso	4	Soroti
Lango	4	Lira
Banana-cotton-finger millet	13	Tororo, Busia and Iganga
Montane	6	Mbale
West Nile	4	Arua

Source: Geresom Okecho, NAADS, Personal communication, 2006.

Data were collected through personal interviews using pre-tested and semi-structured questionnaires specially designed to capture issues related to technology adoption. The survey was administered by trained enumerators supervised by NAADS, NARO and ICRISAT staff from October to December, 2006.

3.3 Socioeconomic profile of target areas

A simple descriptive analysis of the survey data was conducted to identify the basic socioeconomic conditions of farm households (Table 2). About 88% of the sample households were male headed. The mean age of the household heads is about 45 years while the mean education level is about

Table 2. Household socioeconomic characterization.

Socioeconomic issue	Adopters (N=555)	Non-adopters[c] (N=390)	Total (N=945)
Male-headed (%)	88	88	88
Household size	7.21	6.91	7.08
Female workforce[a]	1.39	1.35	1.37
Male workforce[a]	1.19	1.10	1.16
Total workforce[a]	2.58	2.45	2.53
Dependency ratio[b]	2.09	2.10	2.09
Age of household head (years)	45.68	44.91	45.36
Education of household head (years)	7.20	6.73	7.01
Household cumulative education (years)	32.63	29.25	31.24
Value of livestock assets (1000 Ush)	755.00	500.00	650.00
Value of non-livestock assets (1000 Ush)	191.00	183.00	188.00
Own total farm size (ha)	3.20	1.80	2.62
Total own cultivated land (ha)	1.36	0.88	1.16
Nearest all weather road (km)	1.64	1.80	1.71
Nearest village market (km)	1.88	1.68	1.80
Nearest main market (km)	4.44	5.37	4.82
Nearest agricultural information center (km)	2.94	3.92	3.83
Number of owned oxen	0.47	0.16	0.34
Total crop cash income in 2005 (1000 Ush/ha)	377	96	261
Serenut 1 adopters (%)	7	00	4
Serenut 2 adopters (%)	63	00	37
Serenut 3 adopters (%)	33	00	19
Serenut 4 adopters (%)	25	00	15
Igola adopters (%)	15	00	9
Farming as main occupation of HH head (%)	85	78	82
Full time farm labor participation by HH head (% households)	85	78	82
HH belong to community association/group (%)	71	53	63
Ownership of ICT, ie, TV, radio & phone (%)	69	68	68
Bicycle ownership (%)	79	61	71
Tororo district (%)	17	11	14
Busia district (%)	11	19	14
Lira district (%)	15	13	14
Iganga district (%)	15	13	14
Arua district (%)	10	20	14
Mbale district (%)	11	19	14
Soroti district (%)	21	05	14

[a]Workforce = 1*(full time farm labor providing members aged 16-60 years) + 0.5* (Part time farm labor providing members aged 16-60 years) + 0.25* (Full time farm labor providing members aged 11-15 years).

[b]Dependency ratio = (Family size – Total workforce)/Total workforce.

[c]Were households who either grew only local groundnut varieties or did not grow groundnut at all. This means that adopters were therefore households who either grew only improved varieties or grew improved varieties alongside their local varieties.

7 years. The education level is highest in Mbale with 8.7 years and lowest in Soroti with 5.2 years. The average household size for all districts is very high. It ranges from 6.4 in Busia to 8.1 in Mbale, with a mean of 7.1 persons. However, the total work force is relatively low - averaging only 2.5 adult equivalents per family. This indicates high levels of dependency; for every productive member of a household, there were 2 non-productive members. About 82% of the households indicated that agriculture is their main occupation and livelihood strategy.

The households are on average located about 2 km from the nearest village market, 5 km from the nearest main market, and 2 km from the nearest all-weather road. Using distance as a proxy to market access, Iganga has the best access to markets in terms of proximity to main markets while Arua has the worst. If one uses distance to nearest all-weather road, Lira and Mbale districts have better access to markets than others while Busia and Arua have weak market access. Access to agricultural information is important in technology adoption because it creates awareness or reinforces knowledge about an improved technology. Using distance to the nearest research/training center as proxy for access to agricultural information, farmers in Mbale and Iganga have relatively better access than others while Tororo and Busia have poorer access. The majority (68%) of the households also own ICT assets, mainly radio, which is the major means of accessing outside information.

In relation to the asset ownership and wealth status of the surveyed households, the average size of owned farms for all the study districts is about 2.6 ha. The mean value of all non-land assets held by surveyed households is about Ush 838,000 of which livestock assets accounted for about 78%. Livestock is a very important asset among the surveyed households especially in districts where farm size is large and seasonal fallows serve as grazing lands (eg, Lira). Districts with less owned land seem to be investing in non-livestock assets probably due to low availability of pastures for livestock. Mbale district has the highest value of all the non-land assets while Soroti has the highest value of livestock assets. Although Lira district has the largest farm size per household, it does not have the highest mean value of livestock assets, perhaps due to the relative importance of crop production and other structural constraints that limit livestock production (eg, insecurity) in the district.

3.4 Empirical methods

As shown earlier, the adoption decision is essentially a choice between alternative technologies available to the farmer. A farmer will adopt a technology if it maximizes his/her perceived utility (Fernandez-Cornejo et al. 1994). In the absence of limiting constraints, farmers will adopt a technology if the expected benefit from adopting it U_1 is greater than the benefit of using the traditional technology U_0:

15) $U^* = U_1 - U_0 > 0$, where benefits are assumed to be random variables

The probability of adopting the technology may therefore be specified as:-

16) $P(A = 1) = P(U^* > 0) = P(U_1 > U_0)$

The assumption that benefits are random variable implies that U_j, for j = 0, 1, can be written as $D_j + \varepsilon_j$ where D is related to profitability of adopting a technology and ε is the error term. Consequently the probability of adoption can also be written as:

17) $P(U_1 > U_0) = P(D_1 - D_0 > \varepsilon_0 - \varepsilon_1) = P(\varepsilon_0 - \varepsilon_1 < D_1 - D_0)$

This implies that the adoption decision can be modeled as a probit function. That is, the decision by a household to adopt improved technology can be written as:-

18) $P(A = 1) = \Phi(\beta' x)$

where Φ is the cumulative normal distribution, x is a vector of all factors that condition adoption of the technology and β is the vector of coefficients. Hence the adoption of technology j can be specified as (Fernandez-Cornejo et al. 2002):

19) $A_j = \beta' x_j + \varepsilon_j$ *for* $j = 1, 2, \ldots, N$ finite options.

This indicates that when the farmer has the option of choosing between several alternatives, equation (19) may be specified as a system of equations. This, for example, occurs where breeding programs generate several related varieties. Estimation of a single discrete choice model under these conditions will yield inefficient estimates because it disregards the potential cross-equation correlation of the error terms. In order to identify the drivers of technology choice, we therefore estimate an MV probit model, which takes into account the cross-equation error correlations related to adoption of j technologies. The MV probit is an extension of bivariate probit (Greene 1997). It uses Monte Carlo simulation techniques to jointly estimate the multiple probit equation system (Chib and Greenberg 1998, Gates 2006).

As outlined earlier, adoption choices in the context of smallholder agriculture are conditioned by several factors and farmers had to overcome a hierarchy of several constraints (Figure 2). This

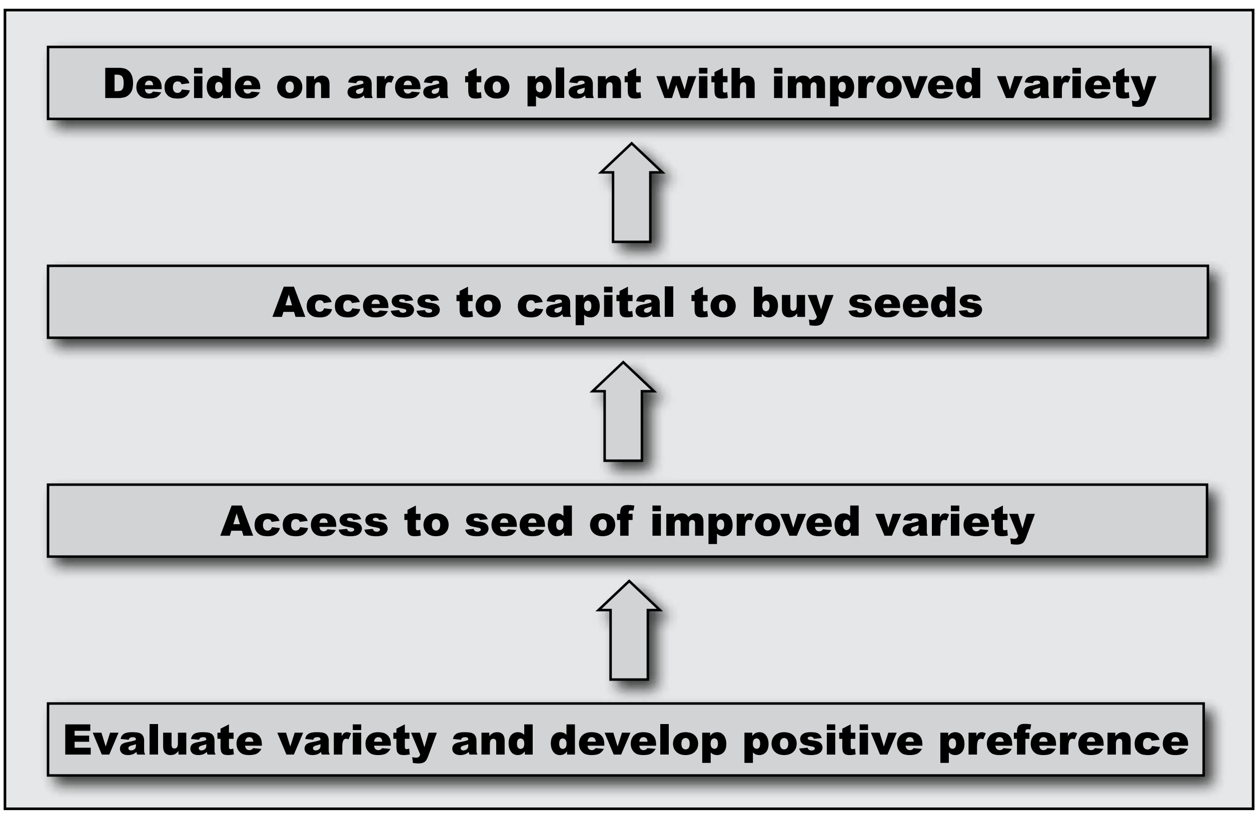

Figure 2: Hurdles farmers must overcome to adopt improved varieties.

implies that even when the expected net gain from adoption is positive, many farmers may not adopt the technology. Under these conditions, adoption of improved varieties entails overcoming a series of obstacles/hurdles that lead to divergence between desired and realized adoption levels (Croppenstedt et al. 2003, Dimara and Skuras 2003, Zavale et al. 2005, Shiferaw et al. 2008). When credit markets are imperfect, poverty in certain assets may determine access to capital and inputs required for adoption. This implies that many farmers with a positive desired demand for improved varieties may not actually adopt new varieties due to limitations in overcoming certain constraints. If households with a positive desired demand cannot adopt the new variety due to certain constraints, econometric models that consider all non-adopting farmers as non-adopters (disinterested in new technology) will provide inconsistent parameter estimates. Application of tobit-type models for this kind of data will provide a corner solution, whereby all zero values for area under the new technology will be regarded as non-adopters.

Our data show that about 59% of the farmers did not face any information, seed supply or capital constraints, had positive demand for new varieties and indeed adopted the technology (group 1). On the other hand, about 8% of the farmers lacked information about the new varieties and hence could not make adoption decisions (group 2). About 18% of the farmers had a positive desired demand for new varieties but had no access to seed (group 3). About 6% wanted to plant new varieties but could not buy seeds due to capital constraints (group 4). Only about 10% of the farmers did not want to adopt the new varieties due to profitability concerns (group 5) (Table 3). This suggests that a constrained adoption model (Cragg 1971, Coady 1995, Croppenstedt et al. 2003) would be more suitable than a tobit model that considers all non-adopters as disinterested in the new technology (Shiferaw et al. 2008).

Table 3. Adoption constraints for groundnut farmers in Uganda.

Choices and constraints	Groundnut adoption choices N	%
1. Want to adopt	777	82.2
Adopted	555	58.7
Lack seed supply	170	17.9
Lack credit	52	5.5
2. Lack information	72	7.6
3. Do not want to adopt	96	10.2
Sample (N)	945	100.0

We therefore estimate a modified double hurdle model with multiple constraints, which benefits from the information about the sample separation. The intensity of adoption is estimated conditional on information, seed access and capital constraints. The four-equation model therefore explicitly takes into account the multiple hurdles that farmers have to overcome before eventually deciding how much land to put under improved varieties (Figure 2). Given that adoption decisions are made under imperfect markets, we include a number of household, farm and institutional factors that capture the differential access to information, credit, labor and other inputs needed in the adoption process. The overall probability of adoption is then computed as a multiple of the probabilities of access to information, positive demand, access to seed supply and availability of capital to invest in new seeds. A descriptive summary of the variables used in the multi-hurdle model is given in Appendix 3.

4. Results

4.1 Farmer awareness and variety adoption

Groundnut is a very popular crop among the farming households in Uganda. About 97% of the households indicated that they have grown groundnut at least once in the past (Table 4), implying that almost all the households have had experience in growing the crop. The results also show that among the surveyed households, about 77% planted groundnuts in the previous season (March/April 2006). Almost 60% of the households indicated that they have grown at least one improved groundnut variety during the previous cropping season. Table 5 presents the results from analysis of farmer awareness, experimentation and adoption of different varieties. Among the improved varieties, the most widely known varieties are Serenut 2 and Serenut 3. About 66% and 46% of the households indicated that they know about Serenut 2 and Serenut 3, respectively. The most widely known traditional variety is Red Beauty. About 47% and 26% of the households have planted Serenut 2 and Serenut 3 before although only 37% and 19% planted Serenut 2 and Serenut 3, respectively, during the 2006 season. About 58% of the surveyed households have planted Red Beauty at least once before while about 26% planted it during the 2006 season. Only about 18% of the households exclusively planted traditional varieties, which indicate that adoption of improved varieties is relatively high.

Table 4. Spread of groundnuts in Uganda (N=945).

Selected indicators	Households (%)
Experience in growing groundnuts	97
Grew groundnuts in March/April 2006 season	77
Has experience in growing improved varieties	70
Grew at least one improved variety last season	59
Grew only improved varieties last season	34
Grew only local varieties last season	18
Grew both improved and local varieties last season	24

Table 5. Groundnut variety knowledge, on-farm experimentation and adoption (N=945).

Groundnut variety	Households knowing the variety (%)	Has experience in growing the variety (%)	Households planted variety last season (%)
Serenut 1	23	10	4
Serenut 2	66	47	37
Serenut 3	46	26	19
Serenut 4	36	20	15
Igola	32	20	9
Red Beauty	70	58	26
Kabonge	41	34	14
Other locals	42	33	12

Table 6 gives the adoption spread of improved groundnut varieties in the different study districts. As expected, Soroti district reported the highest proportion of groundnut growing households in the cropping season preceding the survey. About 93% of all the households that have ever grown groundnuts in Soroti district in the past, did so in the season preceding the survey, of which 84%

Table 6. Groundnut adoption spread across the surveyed districts in Uganda.								
Groundnut issue[a]	Tororo (N=135)	Busia (N=135)	Lira (N=135)	Soroti (N=135)	Iganga (N=135)	Arua (N=135)	Mbale (N=135)	Total (N=945)
Ever grown groundnut	99	93	97	100	97	99	90	97
Ever tried improved varieties	75	70	67	96	73	60	48	70
Grew groundnut last season (March/April 2006)	87	60	82	93	86	63	70	77
Grew improved varieties last season (March/April 2006)	68	45	63	84	63	42	45	59

[a]Variation across the districts was found to be statistically significant at 1%.

planted improved varieties. This high rate of adoption of improved varieties in Soroti district may be attributed to the presence of SAARI, which has the national mandate for groundnut improvement and developed the new RRVs. This district is the primary region where the new varieties are evaluated and tested on-farm. Arua district has the lowest rate of adoption of improved groundnut varieties. Approximately 42% of the respondents in Arua planted improved varieties during the 2006 season.

The intensity of adoption of improved varieties is often assessed by using the proportion of the household's land planted with the variety. Table 7 presents the share of the household's groundnut area allocated to improved varieties. About 62% of the area under groundnut in the survey districts is planted with improved varieties. The district-wise results show that Soroti district had the highest proportion of groundnut area (73%) under improved varieties, followed by Busia and Lira districts (67%). Arua district has the lowest share with 52% of the groundnut area under improved varieties.

Table 7. Groundnut adoption intensity across districts in Uganda (Std. dev in parenthesis).								
Groundnut area	Tororo (N=117)	Busia (N=81)	Lira (N=110)	Soroti (N=125)	Iganga (N=116)	Arua (N=85)	Mbale (N=94)	Total (N=728)
Total groundnut area (ha)	0.711 (0.563)	0.326 (0.241)	0.439 (0.274)	0.416 (0.316)	0.323 (0.257)	0.313 (0.326)	0.376 (0.463)	0.425 (0.391)
Area under improved varieties (ha)	0.433 (0.449)	0.214 (0.209)	0.291 (0.268)	0.287 (0.250)	0.216 (0.286)	0.160 (0.294)	0.250 (0.371)	0.272 (0.325)
Share of improved varieties in total area (%)	57 (36)	67 (42)	67 (41)	73 (33)	58 (42)	52 (43)	57 (45)	62 (41)

Although causality is not necessarily implied, Table 8 compares adopters and non-adopters of improved groundnut varieties using selected variables: acreage, production, marketed surplus and utilization of groundnuts. The average area under groundnuts for adopters is 0.46 ha while non-adopters have about 0.3 ha. In terms of the intensity of adoption, adopters allocate two-thirds of the groundnut area to new varieties. While the relative gain from variety adoption will be evaluated separately using a proper counterfactual for controlling the problem of selection and other pre-existing factors, this descriptive analysis shows that adopters of improved varieties

Table 8. Comparison of adopters and non-adopters of improved groundnut varieties using selected indicators (Std. dev in parenthesis).

Variable	Adopters (N=555)	Non-adopters[a] (N=173)	Total (N=728)
Area under improved varieties (ha)	0.36 (0.33)	0.00 (0.00)	0.27 (0.32)
Area under local varieties (ha)	0.11 (0.17)	0.30 (0.30)	0.15 (0.23)
Total groundnut area (ha)	0.46 (0.41)	0.30 (0.30)	0.42 (0.39)
Net income (1000 USh)	170 (289)	53 (195)	142 (274)
Total dry in-shell production (kg)	377 (447)	173 (269)	329 (421)
Sold groundnuts (% households)	54	35	49
Total in-shell groundnut sold (kg)	111 (234)	66 (208)	100 (229)
Proportion sold (%)	21	17	20
Total dry in-shell consumed on-farm (kg)	74 (96)	40 (66)	66 (91)
Total fresh consumed on-farm (kg)	48 (73)	22 (24)	42 (66)

[a] groundnut growers who only grow local varieties.

allocate more land to groundnut production, have higher output, sell more either in dry or in fresh form (and hence have higher net income). On average, adopters also consume more groundnuts than the non-adopters. These results shed some light on the potential income and nutritional gains to adopters compared to the non-adopters. This analysis is the subject of a separate paper using the same data.

4.2 Economics of groundnut varieties

This section examines the impact of adoption of improved groundnut varieties in terms of simple differences in the economic gains between local and improved varieties. Table 9 compares the yields, revenues, costs and net returns of groundnut production by variety and provides the net gain between improved and local varieties. Improved varieties outperform the local varieties on

Table 9. Comparative economic benefits of different varieties.

Variable	Serenut 1 (N=39)	Serenut 2 (N=355)	Serenut 3 (N=182)	Serenut 4 (N=140)	Igola (N=85)	Improved varieties (N=801)	Local varieties (N=508)	Net benefits from adoption (%)
Yield (kg/ha)	919	1000	919	690	671	888	663	+34
Total gross revenue (1000 USh/ha)	783	852	783	589	572	757	565	+34
Total variable costs(1000 USh/ha)	380	349	392	375	338	364	356	+2
Total net revenue (1000 USh/ha)	403	503	391	213	234	393	209	+88
Variable costs per output (USh/kg)	507	547	776	806	673	656	1180	-44
Returns to investment ratio	1.06	1.44	1.00	0.57	0.69	1.08	0.59	+83

yields and revenues. In particular, the average yield for improved varieties is 34% higher than the average for local varieties. Similarly, farmers growing improved varieties gain 88% higher net income per hectare than those growing local varieties. However, the total variable costs are higher for improved varieties. The total production costs are 2% higher per hectare for improved varieties, although the variable costs per unit of output (ie, per kg) are 44% lower for improved varieties than the local cultivars. These results suggest that although improved varieties have a yield advantage over the local, their production cost is slightly higher. This is not entirely uncommon. Adoption of improved varieties often entails incurring higher labor costs, especially in terms of harvesting, drying and/or shelling (Shiferaw et al. 2008). But despite the slightly higher costs, improved varieties provide a significantly higher income to farmers. In terms of return to investment ratio (ratio of total net revenue and total variable costs), improved varieties are twice as profitable as the local cultivars.

Table 9 also compares the economic benefits of individual improved groundnut varieties. Serenut 2 has the highest yield followed by Serenut 1 and Serenut 3 in the second place. Igola has the lowest yield among the improved varieties. The higher performance of Serenut 2 is attributed to its resistance to the rosette virus and tolerance to drought. At the same time Serenut 2 has the lowest cost of production. Its total variable cost per hectare is USh 349 compared to USh 380 and USh 392 for Serenut 1 & 3, respectively. Consequently Serenut 2 has the highest total revenue and total net revenue among all the improved varieties. Serenut 2 also has the highest return to investment ratio. It has a ratio of 1.44. The second and third best using this indicator of performance are Serenut 1 and Serenut 3, respectively. The many good attributes of Serenut 2 explains its popularity in Uganda.

Groundnut is an important source of cash income for the farming households in the survey districts. About 50% of the groundnut growing households participated in the groundnut markets as sellers. A higher proportion of adopters participated in the markets as sellers (54%) selling about 21% of their groundnut produce compared to 35% of the non-adopters participating in markets selling about 17% of their produce. Overall, 49% of the households who planted groundnuts in the survey districts participated in the market and sold 20% of the total groundnut produce. The difference in the extent of market participation between adopters and non-adopters is probably due to the higher yields obtained by adopters that translate into higher marketable surplus. These results suggest that adopters of improved groundnut varieties are more market-oriented than their counterparts. This is because they have more marketable surplus than their non-adopting counterparts. Adoption of agricultural technologies increases marketable surplus, generates more incomes, reduces aversion to market and production risks and hence increases commercialization (Barrett et al. 2008). It is therefore envisaged that adoption of improved groundnut varieties among groundnut farmers will raise the proportion of farmers selling groundnut and even the volumes marketed.

4.3 Drivers of variety adoption

The MV probit system was estimated jointly for four dependent variables: Serenut 2, Serenut 3, Serenut 4 and Igola.[1] The results are Huber-White heteroscedasticity robust. The *p*-value of the Wald test statistic for the overall significance of the regression is very low indicating that the multivariate probit regression model is highly significant (Table 10).

1. Only a few observations of Serenut 1 were captured by the survey data hence Serenut 1 is excluded from the econometric analysis. As shown in Table 1, less than 7% of the adopters have grown Serenut 1, perhaps indicating its high susceptibility to the rosette virus.

Table 10. Drivers of adoption: multivariate probit regression.				
Variable name (all continuous variables are log form)	Serenut 2	Serenut 3	Serenut 4	Igola
	Coeff	Coeff	Coeff	Coeff
Education (years)	0.027**	0.046***	0.051***	0.027
Sex (Male=1)	-0.039	-0.109	0.063	-0.019
Age (years)	0.493***	0.318*	0.142	0.249
Main occupation (farming =1)	0.332**	0.736***	0.202	-0.077
Female workforce	-0.002	-0.013	-0.002	0.012
Male workforce	0.047**	0.028	-0.009	-0.032
Group membership (yes=1)	0.449***	0.570***	0.445***	-0.066
Distance to market (km)	-0.191***	-0.048	-0.163***	-0.059
Distance to agricultural centre (km)	-0.105***	-0.030	0.035	0.102*
Past crop cash income	0.013**	0.013**	0.003	-0.010
Oxen ownership	0.031	0.103*	0.149***	0.205***
Non-livestock assets (USh/ha)	-0.029	0.021	0.004	-0.026
Livestock assets (USh/ha)	0.020*	-0.008	-0.024**	-0.037***
Farm size (ha)	0.053	0.089*	0.103*	0.134**
Bicycle ownership (yes=1)	0.293**	0.383***	0.335**	0.216
ICT ownership (yes=1)	-0.150	-0.086	-0.178	0.027
Constant	-1.482**	-4.029***	-1.915**	-1.653*
Tororo dummy	-1.018***	1.121***	-0.359*	-0.353
Busia dummy	-1.418***	-0.048	-0.296	-1.033***
Lira dummy	-2.196***	0.560**	-0.614***	0.259
Iganga dummy	-0.831***	0.469*	-1.144***	-1.263***
Arua dummy	-1.487***	0.763***	-0.791***	-0.862***
Mbale dummy	-1.279***	0.017	0.578***	-0.336

Note: *, **, *** denote significance at 10%, 5% and 1% level.

Model performance:

Logpseudo-likelihood = -1405.9873

Prob > chi2 = 0.000

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0:

chi2(6) = 16.9949 Prob > chi2 = 0.0093

An important result is that the correlation coefficients among the error terms are significant indicating that the decision to adopt one variety affects the decision to adopt the others. The only exception is the correlation coefficient of the error terms between Igola and Serenut 4. The correlation between adoption of Serenut 2 and 3, Serenut 2 and 4, and Serenut 3 and 4 as well as that between Serenut 2 and Igola are all positive and significant ($P<0.05$). The correlation coefficient between Serenut 3 and Igola is also significant ($P<0.1$). These results point to the cross-equation correlation of the error terms and hence interdependence in the adoption of improved groundnut varieties. This also indicates that farmers who adopt one improved groundnut variety are also likely to adopt another. The experience of growing one improved variety may offer useful lessons to try and adopt other varieties. These diagnostic tests support the use of multivariate probit regression and indicate that use of simple probit will result in inconsistent estimates.

Table 10 presents the maximum likelihood estimates of the 4-equation MV probit model. Although a similar set of variables seem to explain variety adoption, the MV probit model is more appropriate for estimating the probability of adoption of each variety. The results indicate that among the household characteristics, education, age and farm-orientation have positive and significant effect on the likelihood of adoption of many varieties. Age and education of the head are usually taken as proxies for experience and/or skill and managerial abilities (Dimara and Skuras 2003, Gockowski and Ndoumbe 2004, Asfaw and Admassie 2004). Farmers with more experience with the improved variety and/or better crop management expertise are more likely to adopt new varieties than those lacking in these human capital assets. Family male workforce endowments are positively correlated with the likelihood of adoption of at least one variety. This seems to reflect some degree of imperfection in labor markets in meeting seasonal labor shortages for completing agricultural operations. Reliance on farming as a major source of livelihood seems to increase the probability of adopting new varieties, indicating that such households are most likely to take initiative in the process of local innovation. However, access to off-farm income may in some cases offer opportunities for investing in new technologies and encourage farmers to commercialize production. Contemporaneous off-farm income was not included due to endogeniety concerns. The role of cash availability on variety adoption is captured by past crop cash income, which has a consistent positive and significant effect on variety adoption.

The effect of institutions and access to information (and possibly credit) on variety adoption is captured by participation in farmer organization and distance to agricultural research or training center. As expected, group membership has a significant positive effect on adoption of several varieties. Farmer groups in the area play an important role in sharing information and facilitate access to new seeds. The further away a farmer is located from agricultural information and training centers, the less likely he/she will adopt new technologies or the more likely the local varieties will reign. The positive effect of proximity to NAADS and other agricultural information centers shows also the role that proactive extension can still play in accelerating technological change in smallholder agriculture in Africa. These findings corroborate those of earlier studies that find a positive relationship between access to information and adoption of improved agricultural inputs (Nkamleu and Adesina 2000, Asfaw and Admassie 2004). Similarly, distance to the markets is negatively correlated with variety adoption. This indicates that high transaction costs in accessing improved seeds or selling the surplus produce may substantially reduce the incentive to adopt new varieties.

Among the household assets, farm size, oxen and bicycle ownership have a significant positive effect on adoption. This may be due to better ability to operate the land and plant in time and improved access to markets. This may indicate increased market orientation in the production of groundnuts. The effect of other livestock ownership is not so clear cut – indicating a positive impact on adoption of the popular variety (Serenut 2) but a negative effect on adoption of other cultivars (Serenut 4 and Igola). The positive effect may derive from better ability to hedge production and market risks (Asfaw and Admassie 2004). Wealthier households are less risk averse and are therefore more likely to try and adopt improved technology (Zavale et al. 2005). The negative effect may indicate that increased non-oxen livestock ownership may tend to move more land into grazing or other crops that offer higher byproducts as fodder for livestock.

4.4 Demand for new varieties and intensity of adoption

The results from the multi-hurdle model, where the intensity of adoption of RRVs is estimated conditional on access to information and overcoming the capital and seed supply constraints, are presented in Table 11 and discussed below.

Table 11. Multi-hurdle regression model (std err. in parenthesis).		
Model/Variable	Coefficient	z-statistic
1. Demand for new varieties		
New varieties have preferred taste (yes=1)	0.072 (0.024)	3.020***
New varieties are late maturing (yes=1)	-0.038 (0.027)	-1.430
New varieties have large grain (yes=1)	0.025 (0.023)	1.060
New varieties are high yielding (yes=1)	0.079 (0.028)	2.800***
Male head (yes=1)	0.027 (0.032)	0.840
Education of head 6 to 8 years (yes=1)	-0.030 (0.025)	-1.200
Education of head 9 to 12 years (yes=1)	0.051 (0.029)	1.780*
Education of head more than 12 years (yes=1)	0.122 (0.038)	3.220***
Accessed initial seed from NGOs (yes=1)	0.085 (0.032)	2.620***
Total family workforce	0.009 (0.009)	1.000
Number of owned oxen	0.030 (0.012)	2.580***
Non-oxen livestock wealth (USh 1000/ha)	0.003×10^{-2} (0.000)	-1.750*
Operated farm size per capita (ha)	0.294 (0.028)	10.330***
Fallow area per capita (ha)	-0.014 (0.012)	-1.160
Past experience with new varieties (yes=1)	0.138 (0.025)	5.470***
Distance to village market (km)	0.002 (0.006)	0.390
Distance to main market (km)	-0.003 (0.003)	-0.860
West Nile farming system	-0.147 (0.043)	-3.430***
Teso farming systems	-0.151 (0.045)	-3.350***
Lango farming systems	-0.150 (0.044)	-3.370***
Banana-based systems	-0.108 (0.036)	-3.040***
Constant	0.125 (0.052)	2.410**
2. Information access		
Male head (yes=1)	-0.382 (0.260)	-1.470
Age of head (years)	0.007 (0.006)	1.150
Education of family (yrs)	-0.003 (0.003)	-0.820
Belongs to groups (yes=1)	0.521 (0.149)	3.490***
Had contact with NGOs (yes=1)	4.943 (218.949)	0.020
Distance to agric center (km)	-0.052 (0.022)	-2.360**
Owns bicycle (yes=1)	0.295 (0.170)	1.730*
Owns ICT (yes=1)	-0.107 (0.190)	-0.560
Operated farmsize per capita (ha)	1.631 (0.729)	2.240**
Lira district	-1.624 (0.438)	-3.700***
Tororo district	-1.305 (0.438)	-2.980***
Busia district	-1.109 (0.419)	-2.650***
Iganga district	-1.206 (0.439)	-2.750***
Arua district	-0.005 (0.540)	-0.010
Mbale district	-2.017 (0.430)	-4.690***
Constant	2.323 (0.533)	4.360***
3. Seed access		
Male head (yes=1)	0.087 (0.190)	0.460
Age of head (years)	0.009 (0.004)	2.130**
Farming is main occupation (yes=1)	0.292 (0.160)	1.820*
Belongs to farming group (yes=1)	0.571 (0.142)	4.020***

Continued

Table 11. **Multi-hurdle regression model (std err. in parenthesis)** *continued.*

Model/Variable	Coefficient	z-statistic
Distance to village market (km)	-0.020 (0.036)	-0.550
Distance to agric center (km)	-0.021 (0.017)	-1.220
Accessed initial seed from NGOs (yes=1)	0.583 (0.297)	1.960**
Accessed initial seed from extension (yes=1)	0.937 (0.150)	6.240***
Accessed initial seed from other farmers (yes=1)	0.850 (0.155)	5.490***
Accessed initial seed from markets (yes=1)	0.947 (0.187)	5.060***
Operated farm size per capita (ha)	0.291 (0.375)	0.780
Owns a mobile (yes=1)	0.011 (0.190)	0.060
Owns bicycle (yes=1)	0.327 (0.135)	2.430**
Tororo district	-0.291 (0.255)	-1.140
Busia district	-0.985 (0.243)	-4.060***
Lira district	-0.572 (0.264)	-2.170**
Iganga district	-0.356 (0.269)	-1.320
Arua district	-0.725 (0.234)	-3.100***
Mbale district	-0.505 (0.271)	-1.860*
Constant	-0.614 (0.394)	-1.560
4. Capital access		
Male head (yes=1)	-0.059 (0.278)	-0.210
Belongs to groups (yes=1)	0.498 (0.198)	2.520***
Education of head (yrs)	0.036 (0.024)	1.510
Had contact with NGOs (yes=1)	0.673 (0.366)	1.840*
Distance to main market (km)	-0.024 (0.028)	-0.850
Distance to village market (km)	0.100 (0.078)	1.290
Distance to nearest road (km)	0.066 (0.049)	1.330
Total family workforce	0.006 (0.075)	0.090
Previous crop income (USh 1000/ha)	0.003×10^{-1} (0.001)	0.620
Number of owned oxen	0.142 (0.171)	0.830
Owns transport asset (yes=1)	0.363 (0.199)	1.830*
Operated farm size per capita (ha)	3.965 (1.056)	3.750***
Fallow area per capita (ha)	0.119 (0.205)	0.580
Non-oxen livestock wealth (USh 1000/ha)	0.001×10^{-1} (0.000)	1.030
Has iron roof (yes=1)	-0.063 (0.239)	-0.260
Lira district	-0.174 (0.446)	-0.390
Tororo district	-0.939 (0.388)	-2.420**
Busia district	-0.650 (0.392)	-1.660*
Iganga district	-0.047 (0.432)	-0.110
Arua district	-0.782 (0.360)	-2.170**
Mbale district	-0.505 (0.413)	-1.220
Constant	0.112 (0.440)	0.260
eq5		
Cons	0.264 (0.008)	33.690***
Log likelihood = -866.60886 Wald chi2(21) = 420.89		
Number of obs = 945.00 Prob > chi2 = 0.00		

*; **; *** indicate significance levels at 10%, 5% and 1% level, respectively.

Access to information

Farmer awareness about the availability of new technologies is the critical first step in developing the interest to test and determine its performance relative to other cultivars in use. If there is no access to such information, then the farmer will not have the opportunity to evaluate and choose the technology. The full information assumption therefore ignores the possibility that some of the non-adopters are actually censored due to lack of information, which leads to misleading conclusions. In estimating the demand for new varieties conditional on access to information, we use several variables to explain the variation in accessing information on groundnut technologies. These include gender, age, education, group membership, ownership of ICT, distance to agricultural center, farm size and district fixed effects. Education, group membership, wealth and ownership of means of transport (eg, bicycle) and accessing information (eg, radio and mobiles) are expected to enhance farmer awareness and increase the probability of accessing information on groundnut varieties. As expected, proximity to agricultural centers, group membership, farm size and ownership of a bicycle had a positive and significant effect on the likelihood of accessing information. Interestingly, household education does not seem to affect access to information perhaps because such information is not coming through the print media and does not require high skills to digest and implement. Compared to Soroti, the level of awareness seems to be lower in almost all the other districts.

Access to local seed supply

The seed supply dependent variable is binary – with a value 1 indicating access to local seed supply and 0 representing lack of access irrespective of the capital constraint. We included several household specific, institutional, and regional variables expected to determine access to seed. The institutional variables include linkage to research, extension, markets, farmer-to-farmer seed exchange, and membership in farmer organizations. We hypothesize that farmers with access to information and better contacts with extension services, input markets and farmer organizations or NGOs and research centers will face lower constraints in accessing seed. Indeed the results show that prior experience of obtaining seed from research/extension centers and buying seed from traders have positive and highly significant effects on relaxing the seed access constraint. This indicates that farmers who obtained their initial seed stock from extension and local traders in the past are less likely to maintain good access to improved seed. This may be due to saving and recycling of seed or better relationships that allow farmers to access seed from a particular source. Experience in informal seed systems (farmer-to-farmer seed transfer) also reduces the probability of the farmer facing seed access constraint. In addition, membership in crop production groups significantly reduces the seed access constraint. Similar to findings from other studies, our results underscore the importance of both formal and informal seed systems in technology diffusion in rural areas and networking among farmers in overcoming the problem of access to improved seed (Arega and Manyong 2007, Shiferaw et al. 2008).

Farmers' ability to access improved seeds is also affected by their endowment of certain marketing assets and regional effects. In particular, ownership of a bicycle (a proxy for marketing asset) significantly increases the probability of a farmer having access to improved seeds. This indicates the role of low-cost transport systems in facilitating local mobility and linkages with input and output markets. In rural Uganda, bicycles represent the most important means of transport for moving grain to key markets and inputs to the farm. Rural assemblers often transport over 100 kg of grain procured from the farm to the nearest wholesale markets, offering key services in integrating isolated rural grain markets. Relative to Soroti district, some of the districts (eg, Tororo and Arua) seem to have a lower probability of local access to improved seeds.

Access to capital to buy seeds

The seed requirements for groundnut are quite high (about 120-150 kg/ha). Many small farmers face significant challenges in financing such a high seed requirement. The dichotomous dependent variable takes the value 1 when capital is not limiting adoption, and zero otherwise. The probability of facing a capital constraint in buying improved seed is expected to depend on several household factors (assets, wealth, education, etc), market linkages, past income, social capital, and regional dummies. The key variables reducing the likelihood of facing the capital constraint include group membership, ownership of productive assets (farm size) and means of transport. Membership in a crop production group is highly significant indicating that belonging to such groups improves access to credit for capital-constrained households to finance improved seeds. Such groups are widely used to overcome some idiosyncratic capital and other constraints resulting from imperfections in rural markets. Similarly, farm size substantially reduces the likelihood of facing a capital constraint to finance demand for improved seeds. Other variables related to market access, gender, previous crop income and family education do not seem to have a significant effect on accessing required capital. The regional dummies indicate that relative to Soroti district, Tororo and Arua are more likely to face higher capital constraints.

Demand for improved varieties

Once the capital and seed access hurdles are overcome, a farmer with a positive demand for new varieties will need to decide how much improved seed to use, which determines the extent of technology adoption. The intensity of adoption or the realized demand for improved varieties is therefore modeled conditional on accessing information and overcoming the seed supply and capital constraints. Following previous studies (Sall et al. 2000, Kaliba et al. 2000, Saka et al. 2005, Shiferaw et al. 2008), we investigate the determinants of actual demand (intensity of adoption) for improved varieties using farmland committed to new groundnut varieties. Several variables capturing the effect of farming systems, technology attributes, household characteristics, distance to markets and assets (labor, education, oxen, farm size) were included. The extent of adoption seems to vary by farming system, technology attributes, education, contact with NGOs, ownership of productive assets (oxen and farm size) and prior experience in planting new varieties. From the technology attributes, better taste and higher expected yield increase the intensity of adoption. Among the household assets, higher education, farm size and oxen ownership increase the demand for new varieties. Farmers with past experience and knowledge in growing new varieties of all crops and having regular contact with NGOs seem to have higher demand for new seeds.

Among the institutional variables, membership to crop production groups increases the intensity of adoption of improved varieties. Nevertheless, unlike in the probit adoption model, the proxy variables for market access were not significant determinants of the intensity of variety adoption. The inverse relationship between distance to main market and of the decision to plant new varieties suggest that high transaction costs impede the first-level decisions but not necessarily the degree of adoption of improved technologies. These findings are in line with previous studies on adoption of improved technologies (Feleke and Zegeye 2006 and Salasya et al. 2007).

The results also show that area allocated to improved varieties is affected by household endowment of certain productive assets. The number of oxen and farm size significantly affect the size of land allocated to improved varieties. Unlike in the adoption equation, family labor endowment was not significantly correlated with the intensity of adoption. These findings imply that conditional on overcoming access to information, seed supply and capital constraints, perception of valuable technology traits, possession of key productive assets that ease seasonal resource constraints, social capital, education and prior experimentation with new technologies play an important role in determining the demand for and the actual extent of adoption of improved groundnut varieties in Uganda.

Under a constrained process of adoption, the probability of adopting new RRVs is given as a multiple of probabilities of having access to information, positive demand for new seeds, access to seed supply and the capital required to invest in new technology. Using per capita farm size as the key variable, the effect of these factors on the probability of adoption and the intensity of adoption is presented in Table 12. Since farm size was significant in several of the multi-hurdle model equations, indicating that access to this asset is a key determinant of technology adoption, the probabilities are evaluated for the different values of farm size at the average values of all other model variables. For the lowest value of 0.05 ha per capita, ceteris paribus, the probability of positive seed demand is 69%, that of access to information is 70%, access to seed 52.6%, while probability of access to capital is as low as 1%. This means that for an average land-constrained small farmer, the probability of adoption is very low (0.3%). For group 1 households (adopters) with a similar per capita farm size, the intensity of adoption will be about 0.3 ha. This would be as low as 0.12 ha for information constrained group 2 farmers, but only with a much lower probability of adoption (about 0.3%) (not shown). On the other hand, the probability of adoption would increase to about 14% for an average farm size of 0.2 ha per capita. This would progressively increase to 54% if per capita farm size increases to 1.0 ha, while the intensity of adoption for group 1 farmers would be about 0.58 ha. This shows the importance of farm size and access to information, seed and capital in determining the probability of adoption and area planted into new varieties.

Table 12. Effect of selected variables on probability of adoption and intensity of adoption.

	Probability of					
Cultivated land per capita (ha)[a]	Positive seed demand *(a)*	Access to information *(b)*	Access to seed *(c)*	Access to capital *(d)*	Adoption *(a*b*c*d)*	Intensity of adoption (ha) (for adopters)
0.05	0.690	0.700	0.526	0.010	0.003	0.301
0.10	0.709	0.727	0.532	0.017	0.005	0.316
0.15	0.728	0.754	0.537	0.028	0.008	0.331
0.20	0.746	0.779	0.543	0.043	0.014	0.345
0.25	0.764	0.802	0.549	0.064	0.022	0.360
0.5	0.840	0.896	0.577	0.298	0.129	0.433
1.00	0.940	0.981	0.633	0.927	0.541	0.580
1.50	0.983	0.998	0.687	0.999	0.673	0.727
2.0	0.996	0.999	0.736	0.999	0.732	0.874

[a]About 30% of the farmers have per capita farm size less than 0.1 ha, 64% have less than 0.2 ha, 82% have less than 0.3 ha, 90% have less than 0.4 ha, and 95% have less than 0.5 ha. Only 5% of the sample households had above 0.5 ha.

5. Conclusion

This paper examines the factors affecting the decision to adopt and the intensity of adoption of improved groundnut varieties in Uganda. Imperfect information, seed access and capital constraints are some of the key factors that determine technology adoption by smallholders. Many past studies assume that non-adopting farmers make decisions for non-use of the technology under full information. In addition, all non-users of the technology are assumed to be disinterested in the innovation after having made a comparative assessment of its performance on-farm. Failure to account for lack of information to make informed choices and to separate those who have a positive desired demand for new technology but constrained from using it would lead to inconsistent parameter estimates and misleading conclusions. Furthermore, under conditions where farmers could choose from alternative cultivars, the choice of one variety may depend on the choice of the others, making univariate and single-equation approaches less suitable.

In studying the adoption behavior of smallholder groundnut farmers in Uganda, the paper uses two procedures that address these estimation and model-specification issues. First, it uses the multivariate probit model that explicitly treats the error correlation in the decision by farmers to adopt different improved varieties. Second, the paper models the adoption process as a flexible multi-hurdle model that takes into account various constraints facing farmers – information, seed supply and capital access.

The results from the multivariate regression analysis indicated that the variety adoption choices are correlated implying that joint estimation is appropriate and single probit/logit specifications would yield inefficient standard errors. The results of the heteroscedasticity-robust estimates suggest that farmer-specific factors (eg, age, education and workforce), institutional factors (eg, market access and participation in farmer organizations) and endowment with human, physical and financial capital are key drivers of adoption of improved groundnut varieties in Uganda. However, the marginal effect of these variables differs across the different improved groundnut varieties, but farmers with more experience, education, access to information, markets, capital and participating in farmer groups are more likely to adopt popular varieties.

We also find unique insights on the importance of imperfect information, capital and seed access constraints in conditioning the intensity of adoption of improved varieties. About 8% of the farmers lack information about new varieties and hence could not make any adoption decisions. About 18% want to plant new varieties but did not adopt mainly due to lack of local supply while some 6% were constrained by lack of capital to buy seeds. The multi-hurdle regression analysis was used to identify the specific factors that determine access to information, seed supply and capital constraints and the overall demand for new varieties conditional on overcoming these hurdles. Participation in farmer groups and distance to information centers are critical for accessing variety information. Seed supply constraints are overcome by good links with local seed sellers, extension and membership in seed production groups. Interestingly, we also find group membership to be a key factor in overcoming capital constraints. Productive assets like bicycles and farm size were also related to improved access to information, seed and capital, which enables adoption of new varieties. The importance of market access, household assets, human capital and farm size in overcoming certain constraints to adoption indicates that in the absence of public intervention resource-poor and marginal farmers lacking in terms of these vital assets may lag behind or face stiff barriers that may exclude them from harnessing new technologies. This may lock some households into stagnating subsistence farming and extreme poverty.

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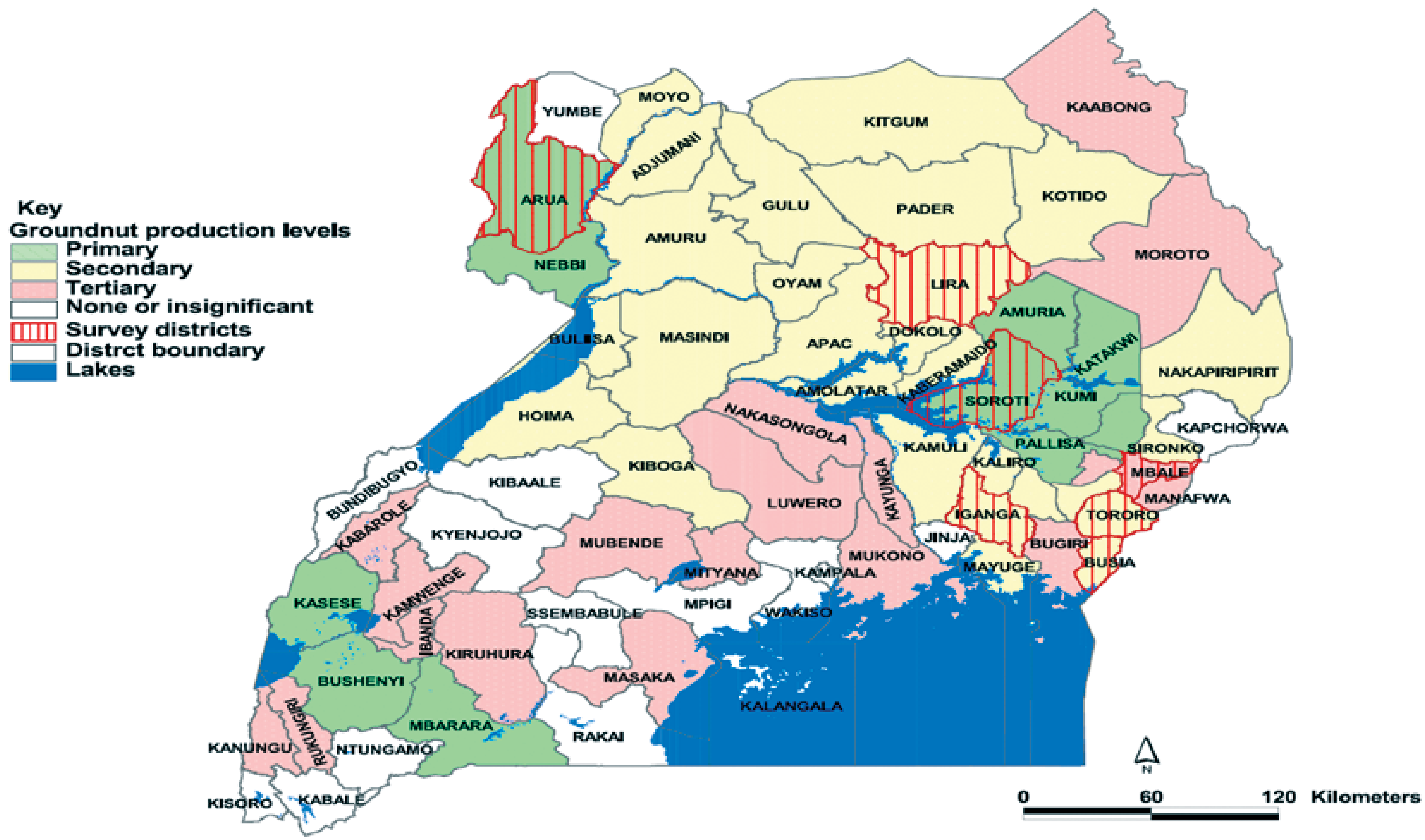
Appendixes

Appendix 1. Improved groundnut varieties released in Uganda.

Variety	Year of release	Important traits
Igola	1995	Virginia type Highly resistant to rosette Highly tolerant to drought 1–2 seeds per pod Large and bold brown/white seeds Yield potential of 2,500–3,000 kg/ha Matures in 120–130 days (long duration) About 48% oil content Has slightly bitter taste
Serenut 1 (ICGV-SM 83708)	1999	Virginia type Highly susceptible to rosette Moderately tolerant to drought Matures in 100–110 days (medium duration) Yield potential of 3,000–4,000 kg/ha Large and reddish-colored seeds About 43% oil content Has slightly sweet taste
Serenut 2 (ICGV-SM 90704)	1999	Virginia type Highly resistant to rosette Highly tolerant to drought Matures in 100–110 days (medium duration) Yield potential of 3,000–3,500 kg/ha 1–2 seeds per pod Brown to tan-colored seeds About 40% oil content Has slightly sweet taste Hard shell, thus difficult to shell
Serenut 3 (ICGV-SM 93530)	2002	Virginia type Resistant to rosette Tolerant to drought Matures in 90–100 days (short duration) Yield potential of 2,500–3,000 kg/ha 1–2 seeds per pod Small and reddish-colored seeds About 47% oil content Has slightly bitter taste
Serenut 4 (ICG 12991)	2002	Spanish type Resistant to rosette virus vector *Aphis craccivora* Moderately tolerant to drought Matures in 90–100 days (short duration) Yield potential of 2,500–3,000 kg/ha Tan-colored seeds About 43% oil content Has sweet taste (good for snacks)

Source: Nalyongo Watiti and Busolo-Bulafu, SAARI, personal communication 2007.

Appendix 2. Groundnut production in Uganda and sample districts.



Appendix 3. Descriptive statistics for the variables used in the multi-hurdle regression model.

Variable	Group 1: Adopters 58.7%		Group 2: Lack information 7.6%		Group 3: Want to adopt but seed constrained 18.0%		Group 4: Want to adopt but capital constrained 5.5%		Group 5: Do not want to adopt 10.2%	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Improved variety area (ha)	0.357	0.329	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aware of technology (yes=1)	1.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Seed supply unconstrained (yes=1)	1.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
Capital unconstrained (yes=1)	1.000	0.000	1.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000
New varieties have preferred taste (yes=1)	0.366	0.482	0.000	0.000	0.047	0.212	0.096	0.298	0.031	0.175
New varieties are late maturing (yes=1)	0.173	0.379	0.236	0.428	0.153	0.361	0.173	0.382	0.198	0.401
New varieties have large grain (yes=1)	0.373	0.484	0.000	0.000	0.112	0.316	0.135	0.345	0.031	0.175
New varieties are high yielding (yes=1)	0.937	0.243	0.000	0.000	0.194	0.397	0.212	0.412	0.063	0.243
Farming is main occupation (yes=1)	0.850	0.357	0.611	0.491	0.800	0.401	0.865	0.345	0.813	0.392
Male head (yes=1)	0.879	0.326	0.931	0.256	0.859	0.349	0.846	0.364	0.896	0.307
Age of head (years)	45.676	13.531	45.708	13.252	44.800	13.463	47.808	15.161	42.948	12.165
Education of head 6 to 8 years (yes=1)	0.344	0.476	0.292	0.458	0.306	0.462	0.385	0.491	0.333	0.474
Education of head 9 to 12 years (yes=1)	0.247	0.432	0.306	0.464	0.182	0.387	0.173	0.382	0.219	0.416
Education of head > 12 years (yes=1)	0.103	0.304	0.194	0.399	0.082	0.276	0.038	0.194	0.094	0.293
Education of head (yrs)	7.202	4.052	8.514	4.179	6.241	3.990	5.769	4.008	6.771	4.194
Education of family (yrs)	32.632	22.879	37.750	27.627	27.341	20.210	26.077	18.235	28.177	18.999
Belongs to groups (yes=1)	0.706	0.456	0.458	0.502	0.529	0.501	0.481	0.505	0.594	0.494
Belongs to farming group (yes=1)	0.634	0.482	0.250	0.436	0.388	0.489	0.385	0.491	0.490	0.503
Total family workforce	2.585	1.227	2.601	1.531	2.391	1.156	2.428	1.305	2.456	1.269
Operated farm size per capita (ha)	0.245	0.498	0.123	0.104	0.152	0.121	0.115	0.086	0.159	0.148
Fallow area per capita (ha)	0.296	1.104	0.092	0.140	0.172	0.246	0.136	0.157	0.166	0.258
Past experience with new varieties (yes=1)	0.793	0.406	0.000	0.000	0.365	0.483	0.365	0.486	0.125	0.332
Distance to main market (km)	4.438	3.412	4.774	2.802	5.750	3.826	5.274	3.302	5.180	4.578
Distance to village market (km)	1.878	1.920	1.472	1.622	1.778	1.720	1.259	1.268	1.909	1.729
Distance to agric center (km)	3.631	3.325	3.615	3.847	4.256	3.931	4.038	4.063	4.282	4.391
Distance to nearest road (km)	1.641	2.136	1.393	2.048	1.987	2.259	1.663	1.561	1.853	2.825
Accessed initial seed from NGOs (yes=1)	0.157	0.364	0.000	0.000	0.029	0.169	0.038	0.194	0.021	0.144
Accessed initial seed from extension (yes=1)	0.517	0.500	0.000	0.000	0.159	0.367	0.135	0.345	0.073	0.261
Accessed initial seed from farmers (yes=1)	0.351	0.478	0.000	0.000	0.165	0.372	0.154	0.364	0.042	0.201

Continued

Appendix 3. Descriptive statistics for the variables used in the multi-hurdle regression model *continued.*

Variable	Group 1: Adopters 58.7%		Group 2: Lack information 7.6%		Group 3: Want to adopt but seed constrained 18.0%		Group 4: Want to adopt but capital constrained 5.5%		Group 5: Do not want to adopt 10.2%	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Accessed initial seed from markets (yes=1)	0.209	0.407	0.000	0.000	0.082	0.276	0.077	0.269	0.031	0.175
Number of owned oxen	0.468	1.106	0.139	0.612	0.176	0.674	0.077	0.388	0.198	0.592
Non-oxen livestock wealth per ha (1,000)	365.701	651.039	481.016	523.124	256.034	398.166	417.657	673.919	357.497	567.241
Previous crop income per ha (1,000)	376.933	6378.001	166.860	891.132	87.658	262.691	71.198	191.314	71.485	112.617
Has iron roof (yes=1)	0.441	0.497	0.708	0.458	0.324	0.469	0.385	0.491	0.313	0.466
Owns transport asset (yes=1)	0.804	0.398	0.583	0.496	0.600	0.491	0.577	0.499	0.750	0.435
Owns bicycle (yes=1)	0.791	0.407	0.556	0.500	0.576	0.496	0.558	0.502	0.729	0.447
Owns ICT (yes=1)	0.690	0.463	0.806	0.399	0.600	0.491	0.596	0.495	0.760	0.429
Owns a mobile (yes=1)	0.153	0.360	0.250	0.436	0.124	0.330	0.154	0.364	0.167	0.375
West nile farming system	0.103	0.304	0.014	0.118	0.229	0.422	0.250	0.437	0.260	0.441
Teso farming systems	0.205	0.404	0.014	0.118	0.076	0.267	0.096	0.298	0.021	0.144
Lango farming systems	0.153	0.360	0.139	0.348	0.100	0.301	0.038	0.194	0.219	0.416
Banana-based systems	0.429	0.495	0.347	0.479	0.435	0.497	0.442	0.502	0.469	0.502
Lira district	0.153	0.360	0.139	0.348	0.100	0.301	0.038	0.194	0.219	0.416
Tororo district	0.166	0.372	0.097	0.298	0.100	0.301	0.173	0.382	0.104	0.307
Busia district	0.110	0.313	0.139	0.348	0.241	0.429	0.173	0.382	0.146	0.355
Iganga district	0.153	0.360	0.111	0.316	0.094	0.293	0.096	0.298	0.219	0.416
Arua district	0.103	0.304	0.014	0.118	0.229	0.422	0.250	0.437	0.260	0.441
Mbale district	0.110	0.313	0.486	0.503	0.159	0.367	0.173	0.382	0.031	0.175
Soroti district	0.205	0.404	0.014	0.118	0.076	0.267	0.096	0.298	0.021	0.144

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

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