Assessment of the Adoption and Impact of Improved Pigeonpea Varieties in Tanzania

Bekele Shiferaw, Said Silim, Geoffrey Muricho, Patrick Audi, Joseph Mligo, Stephen Lyimo, Liangzhi You and Jørgen L Christiansen

International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India

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Introduction

The pigeonpea economy in Tanzania

Pigeonpea (Cajanus cajan) is an important grain legume in the semi-arid regions of Tanzania. The crop offers multiple benefits – protein rich seed (approximately 21% protein), fuel, fodder, fencing material, improved soil fertility and erosion control. It ranks third among the pulses (after beans and cowpea) in total national production (Mligo 1994; Lyimo and Myaka 2001). According to FAO statistics, pigeonpea accounted for about 11% of the total annual production of pulses in the country between 1992 and 2000 (Table 1). This data also indicates that though pigeonpea is third to beans and cowpea in production, its production share in total national production of pulses is very close to cowpea.

Table 1. Mean annual production, cultivated area and share of pulses in Tanzania (1992–2000).

Crops	Production (1000 t)	Share (%)	Cultivated area (1000 ha)	Share (%)
Beans	241.1	60.5	350.6	47.4
Cowpea	44.1	11.1	146.0	19.7
Pigeonpea	44.0	11.0	62.9	8.5
Other pulses	69.2	17.4	180.7	24.4
Total pulses	398.4	100.0	740.1	100.0

Source: FAOSTAT (2004).

The crop is grown in several parts of the country. The major growing areas are Lindi and Mtwara regions in the southern zone; Kilimanjaro, Arusha and Manyara regions in the northern zone; and Shinyanga region in the Lake Zone. The crop is also grown along the coast, Dar es Salaam, Tanga and in Morogoro regions in the eastern zone where it is used mainly as a vegetable (green peas). About 14 districts are primary producers mainly located in the southern and northern zones of the country (Appendix 1). In these districts, pigeonpea is mainly harvested and consumed or sold as dry grain, while it is mainly harvested at the green stage and consumed as a vegetable (green peas) in the secondary production areas. In the northern zone districts including Babati, pigeonpea is mainly grown as a cash crop. Traditionally, the farmers in the northern zone prefer to consume other legumes such as beans and cowpeas while their counterparts in the southern zone districts lack these alternative food sources and therefore use a larger share of their pigeonpea produce for home consumption. The quality of pigeonpea from the northern zone districts is also considered to be superior and hence more suited for the export market, especially the large and white colored grains grown in Babati.

Pigeonpea production trends in the country are shown in Table 2. It is very difficult to find time series trade data for pigeonpea from the official national trade statistics. In several trade statistics, pigeonpea is lumped together with peas, pulses or legumes. Although the export figures shown in Table 2 may not fully reflect the total volume of pigeonpea exported from Tanzania, the data shows that it is an important pulse crop that earns foreign exchange for the country. If the productivity and the quality of production can be improved, pigeonpea can be an important legume in the agricultural economy of Tanzania and a valuable source of cash, nutrients and livelihoods for small producers.

Table 2. Area, production, yield and exports of pigeonpea in Tanzania.

Year	Area (1000 ha)	Production (1000 t)	Yield (t/ha)	Exports (1000 t)[1]
1992/93	55	38	0.69	23.39
1993/94	50	34	0.68	22.80
1994/95	60	42	0.70	27.69
1995/96	79	55	0.70	34.61
1996/97	60	41	0.68	25.69
1997/98	65	45	0.69	27.13
1998/99	65	47	0.72	28.58
1999/00	66	47	0.71	29.41
2000/01	66	47	0.71	30.29

1. Estimates compiled from various sources (this data was not available from FAOSTAT).
Source: FAOSTAT (2004).

Pigeonpea research and development

Several studies in Tanzania showed that pigeonpea production was not growing as fast as other pulses in the country (Mligo 1994; Lyimo and Myaka 2001; ICRISAT 2004). In fact, in some areas production was declining tremendously and even farmers were abandoning pigeonpea cultivation altogether mainly due to fusarium wilt – a soil borne fungal disease that is very devastating for the crop. The fungus (Fusarium udum) survives on the debris of infected plants in the soil and its main symptom is patches of dead plants at the flowering and podding stages. Partial wilting of the plant is a definite indication of this disease. Ratooning also predisposes the plant to this wilt and it has been documented that long and medium duration varieties suffer more from fusarium wilt than the short duration varieties (Reddy et al. 1993).

There are ways for controlling the disease but are quite expensive for cash- and labor-constrained smallholder producers. The control measures include selection of fields that are free from the disease, use of disease-free seeds, planting resistant varieties and rotating and/or intercropping of pigeonpea with cereals such as sorghum. These practices are both resource and knowledge intensive and small farmers often find it difficult to control the disease especially when the rate of field infestation is high. In Tanzania, the disease is widespread in all pigeonpea growing areas and it is of enormous economic importance. If uncontrolled, the disease can cause a major loss in productivity. Joint assessments by ICRISAT and NARS indicated that in the 1980s economic losses in pigeonpea due to fusarium wilt were about 470, 000 t of grain in India and 30,000 t of grain in Africa (Joshi et al. 2001). As far back as in the early 1960s, the disease was singled out as the main pigeonpea production constraint in Tanzania (Kimani 2001). In 1988, a farmer survey in Kilosa District showed that fusarium wilt was still the main constraint in pigeonpea production with its incidence ranging from 10 to 96% on the farmers' fields (Mbwaga 1995). As a follow up to the survey results, a screening program for fusarium wilt resistance was initiated again as a concerted effort between ICRISAT and DRD in the early 1990s. The main thrust of this research was to stabilize the extreme variability in pigeonpea yields by developing fusarium-resistant varieties that can also mature early thus escaping the terminal drought that often reduces the yields of the late maturing local landraces.

In order to address the region-specific production constraints for pigeonpea, ICRISAT initiated a regional breeding program to ensure that the varieties developed were adapted to the growing conditions in East Africa. In 1991, the ADB provided funding to ICRISAT to implement this program with a resident scientist based in ICRISAT-Nairobi. This has made it possible to initiate a collaborative research program with NARS in the region. The research aimed to develop varieties that are resistant to fusarium wilt, able to meet end user preferences (farmers and markets) and adaptable to the agro-climatic conditions in the region. In terms of market traits, the focus was on varieties with large white/cream seeds. Since local varieties take long to cook, many consumers prefer fast cooking grains with good aroma. Farmers also prefer the relatively early maturing types so that they can escape terminal drought. For agro-climatic adaptation, altitude and photoperiod sensitivity were considered. Long duration varieties were targeted for medium and high altitude areas such as northern Tanzania. Medium and short duration types were targeted for low and medium elevation areas.

The collaboration was later expanded to include development partners such as TechnoServe and the CRS who provided significant contributions in developing farmer and market-preferred pigeonpea varieties. By 1997, this effort resulted in the development of 21 varieties of long, medium and short duration types that were successfully tested on-station. Appendix 2 shows the list of varieties and their attributes vis-à-vis the local landraces. Contrary to the traditional research where little consideration of farmers' and consumers' preferences were factored in during the selection of improved varieties, farmers and private sector traders in this particular case were involved in on-station breeding and variety selection activities. The varieties were subsequently evaluated on farmers' fields. In collaboration with ICRISAT and SARI, the DRD of Tanzania started participatory on-farm testing and evaluation of these promising varieties in the mid-1990s. The participatory farmer evaluation helped to identify a set of key traits that would be needed to develop varieties that meet end-user needs. During the on-farm evaluation, participating farmers were asked to rank the pigeonpea traits, which they considered important (Table 3). This information was in turn used in identifying the best-bet interventions that are resistant to fusarium wilt and would provide higher relative returns to small farmers.

Table 3. Important criteria used by farmers to select pigeonpea varieties.

Criterion	Rank	Criterion	Rank
High yield	1	White grain colour	6
Disease resistance	2	Drought tolerance	7
Pest resistance	3	Large grains	8
Early maturity	4	Medium plant height	9
Even/uniform maturity	5		

Source: ICRISAT (2003).

The most important attributes to farmers in decreasing order were yield, disease and pest resistance, and early maturity. ICEAP 00040, the most preferred improved variety, was selected by the farmers in Babati due to its higher yields and resistance to fusarium wilt.

Variety testing and evaluations were conducted in almost all the major pigeonpea producing areas of the country. The short duration varieties were evaluated in Morogoro, Tanga, Dar es Salaam, Lindi and Mtwara, while the medium and long duration varieties were tested in Morogoro, Lindi, Kilimanjaro, Mtwara and Arusha Regions (Lyimo and Myaka 2001). In addition, demonstrations and field days were undertaken for promotion of farmer-preferred varieties. So far, a total of three varieties that resulted from this research investment were released in Tanzania (Table 4). Other varieties such as ICEAP 00053 and ICEAP 00557 are in the process of being released.

Table 4. Pigeonpea varieties released in Tanzania.

Variety	Duration	Year of release	Release name
ICPL 87091	Short	1999	Komboa
ICEAP 00040	Long	2002	Mali
ICEAP 00068	Medium	2003	Tumia

Source: Lyimo and Myaka (2001); Silim, ICRISAT, personal communication (2004).

However, to date, there has been no study to assess the level of adoption of these improved pigeonpea varieties and constraints to adoption in Tanzania. The economic impact of this research investment to smallholder pigeonpea growers and consumers in Tanzania is not known. Using empirical data from Babati where the technologies were initially tested and the released variety ICEAP 00040 is grown relatively widely, this study aimed to evaluate the level of uptake, the determinants of varietal uptake and the economic impact of this research investment to Tanzania.

The study was undertaken with the following objectives:

1. Assess the breadth and depth of adoption of improved pigeonpea varieties in the area.
2. Identify the policy relevant factors influencing the adoption of improved pigeonpea varieties and quantify their influence.
3. Assess the potential economic and social impacts of improved pigeonpea varieties for adopting farmers as well as producers and consumers in the rest of Tanzania.

Characteristics of the study area

The study was undertaken in Babati, one of the five districts in Manyara region carved out recently from the then larger Arusha region in the northern zone of Tanzania. The other four districts in Manyara region are Mbulu, Hanang, Simanjiro and Kiteto. In this region, Babati is the leading producer of pigeonpea followed by Mbulu, Hanang, Simanjiro and Kiteto. The district accounts for about a third of the total area and total production of pigeonpea in Tanzania (Table 5). The district also accounts for 45% of the pigeonpea export in Tanzania. The average yield is about 0.77 t/ha compared to about 0.70 t/ha in the country as a whole.

Administratively, Babati has four divisions, which are further divided into wards and then villages. According to their order of importance the major divisions in pigeonpea production are Gorowa, Babati, Bashnet and Mbugwe. Market access in terms of the road network is relatively better in Gorowa and Babati divisions compared to Bashnet and Mbugwe. The district covers 6069 sq km with a landscape that ranges between 900 and 2000 m above sea level. The climate is mild and semi-arid where days are hot and dry while nights are chilly. The district receives bimodal rainfall ranging between 300 and 1200 mm per year. Short rains occur between October and January while the long rainy season lasts between February and May. The long-term (1970– 95) average precipitation for the district is 790 mm/year. The predominant soils are red and black where crops such as maize, wheat, rice, beans and pigeonpeas are grown. The district is inhabited by a number of ethnic groups with more than five spoken languages. The social complexity is because of recent immigrations and a very long history of human habitation (Simonsson 2001). The socioeconomic and biophysical characteristics of the district are summarized in Table 6. Rainfall is highest in Bashnet and Babati divisions and lowest in Mbugwe. In terms of overall poverty levels, Gorowa and Babati seem to be better endowed than Mbugwe while Bashnet seems to fall between the two groups.

Table 5. Area, production and marketed/exports of pigeonpea ('000) in Tanzania.

Year	Babati District Area (ha)	Babati District Production (t)	Babati District Marketed/ exported (t)	Rest of Tanzania Area (ha)	Rest of Tanzania Production (t)	Rest of Tanzania Marketed/ exported (t)	Tanzania Area (ha)	Tanzania Production (t)	Tanzania Marketed/ exported (t)
1992/93	11.03	9.92	8.83	43.97	28.08	15.44	55.00	38.00	23.39
1993/94	17.87	16.33	14.53	32.13	17.67	9.72	50.00	34.00	22.80
1994/95	19.74	18.28	16.27	40.26	23.72	13.05	60.00	42.00	27.69
1995/96	19.64	17.36	15.45	59.36	37.64	20.70	79.00	55.00	34.61
1996/97	12.91	12.50	11.12	47.09	28.50	15.68	60.00	41.00	25.69
1997/98	14.91	9.47	8.43	50.09	35.53	19.54	65.00	45.00	27.13
1998/99	19.15	10.88	9.68	45.85	36.12	19.87	65.00	47.00	28.58
1999/00	27.85	14.17	12.61	38.15	32.83	18.06	66.00	47.00	29.41
2000/01	22.14	17.70	15.75	43.86	29.30	16.12	66.00	47.00	30.29
Average	18.36	14.07	12.52	44.53	29.93	16.46	62.89	44.00	27.73

Source: Compiled from different sources like FAOSTAT (2004) and field surveys in Babati (2004).

Table 6. Socioeconomic and biophysical characteristics of Babati district.

Socioeconomic and biophysical characteristics	Administrative Divisions: Gorowa	Babati	Bashnet	Mbugwe
1. Altitude (m)	1200–1500	1500–1800	1800–2200	900–1200
2. Agro-ecological zone	4 (Semi-humid midlands)	3 (Semi-humid uplands)	2 (Humid highlands)	5 (Semi-arid lowlands)
3. Rainfall (mm/year)	750–900	900–1100	1100–1200	500–700
4. Soils	Fertile sandy loams and black clays	Fertile volcanic loams	Sandy loams with medium fertility	Sandy soils
5. Relative wealth status of rural households	Better	Better	Medium	Poorer

Source: Based on DALDO reports and personal communication with DALDO, Babati district.

The main economic activity in the district is peasant agriculture and pastoralism. Babati town is about 1500 m above sea level and is connected with Arusha (about 650 km from Dar es Salaam) through a 164 km road that is laid with tarmac and all-weather gravel road. The town has hydroelectric power supply and access to telephone and fax connections to main urban centers and the rest of the world. These facilities are not available to farmers and other rural residents in the district.

Impact assessment methodology

Tracking the uptake of new technologies and their impacts to producers and consumers in a given setting is a complicated and data-intensive undertaking. Proper impact evaluation requires baseline data from a representative sample that will help the evaluator establish the benchmark before the intervention. Regular monitoring and evaluation studies undertaken during the lifetime of the project along with socioeconomic data generated at different points of the project cycle will then be used to track the changes attributable to the project (Baker 2000). As is typically the case for many impact assessment studies, there was no baseline data collected in this project. This has precluded the possibility of using the before and after approach of comparing the same households in tracing changes associated with the adoption of the varieties. The approach used for this study is to gather data from both adopting and non-adopting households so that the impact of the interventions can be estimated by comparing sample households with and without the technology. A survey was undertaken in selected divisions of Babati during July and August 2004. This approach was used partly because in addition to evaluating the economic impacts, the study also aimed to understand the adoption process and identify the policy-relevant factors that condition variety choice and uptake decisions.

Sampling framework

The survey in the district was carried out in three steps. First, a team of researchers from ICRISAT along with local partners conducted an exploratory survey to acquire a broad overview of the process and pattern of pigeonpea variety adoption and impacts in the district. During this preparatory survey, key informants including extension officers based at the district, division and village levels, and farmers were consulted. Secondary information from the district agricultural office was also collected. The information gathered at this stage formed the basis for formulating the survey instrument (questionnaire) and design of the sampling framework. In the second stage, the team tested the questionnaire with selected farmers in the villages. In the third stage, the team adjusted the instrument based on the lessons learnt from the field-testing and carried out the survey using trained enumerators from DALDO and SARI.

Stratified multi-stage sampling was used to select the respondent farmers. First, the 21 administrative wards in the district were classified into four strata based on variety adoption levels estimated during the exploratory survey and from data provided by the key informants (Table 7).

Sampling of adopters and non-adopter was done in the adopting wards ie, strata 1-3. Babati and Singe, the only wards in the first and second strata, were automatically selected while Bonga ward was randomly selected from the third strata (Tables 7 and 8). Two villages were subsequently randomly selected from each of the selected wards for an in-depth study. A list of all the resident households from each of the selected villages was prepared and 40 households were randomly sampled from them (Table 8).

Table 7. Initial estimated adoption levels for improved pigeonpea varieties in the different wards of Babati district.

Adoption level	No. of wards	No. of households
High (>50%)	1	6806
Medium (20–50%)	1	1618
Low (5–20%)	2	4743
Non-adopting (<5%)	17	46803

Source: Based on key informants in the district.

Table 8. Sample villages and sample size.

Adoption strata	Division	Ward	Village	Sample
High (>50%)	Babati	Babati	Nangara	40
			Bagara	40
Medium (20–50%)	Gorowa	Singe	Singe	40
			Managhat	40
Low (5–20%)	Gorowa	Bonga	Nakwa	40
			Bonga	40
Total				**240**

The questionnaire used for the survey was designed to generate information on socioeconomic characteristics of farm households, asset ownership, economics of pigeonpea production, farmer preferences about improved varieties, adoption of improved varieties, constraints to adoption, and crop and livestock production practices. Besides, the data on utilization of pigeonpea, including consumption and marketing decisions was collected. Production and yield data was collected only for the 2002/03, mainly because the 2003/04 crop was not yet harvested during the survey.

The spread and depth of adoption of improved varieties were estimated using simple statistical methods. The proportion of sample farmers growing the improved varieties is used as a proxy to estimate the spread or diffusion of the technology. The proportion of cultivated land allocated to the improved varieties is used to estimate the depth or intensity of adoption. Returns to smallholders from adoption of the improved varieties are estimated as the difference in net income between the new and traditional varieties and by comparing the net returns per unit of investment between the two varieties. This shows the relative profitability of the new technology and the potential economic incentives to farmers who make decisions on the choice of the pigeonpea technologies.

Analytical methods for determinants of adoption

Several econometric models have been developed by economists to study the adoption behavior of farmers and to identify the key determinants of technology adoption. The selection of the econometric model to be used largely depends on the purpose of the study and the type of adoption data available. When the dependent variable is dichotomous and the purpose is to investigate the probability of adoptions and how the likelihood of adoption changes when certain policy variables change, probit and logit models are commonly used. With ordered categorical dependent variables, ordered probit and logit specifications have been used (eg, Shiferaw and Holden 1998). With multiple-choice type and unordered discrete dependent responses, a multinomial logit specification is most appropriate (Greene 1997). In our case, the dependent variable measured in terms of the share of cultivated land allocated to improved pigeonpea varieties is continuous but observed only when the farmer in fact adopted the technology. In other words, the dependent variable is censored or limited from below at level zero for non-adopters. If one uses the sub-sample where the dependent variable is observed (Y>0), the ordinary least squares (OLS) estimates will be biased and inconsistent. In such case, the dependent variable is zero for a significant fraction of the sample. The conventional regression methods that assume a continuous normal distribution fail to account for the qualitative difference between limit (zero) observations and non-limit (continuous) observations. For censored data, the most appropriate method is a mix of discrete and continuous distributions. Therefore, the censored regression model also called Tobit model (Tobin 1958) was used for this analysis.1

The general formulation of this model is given as

$$Y_i^* = X_i' \beta + \varepsilon_i$$
$$Y_i = 0 \text{ if } Y_i^* \leq 0$$
$$Y_i = Y_i^* \text{ if } Y_i^* > 0$$

where Y* is a latent variable indexing adoption that is observed if Y* > 0 and not observed if Y* ≤ 0, Y is an observable but censored variable measuring both the probability of adopting and intensity of adopting improved varieties, ß is a vector of unknown parameters, Xi is a vector of independent variables and ei is the residuals that are independently distributed with zero mean and constant variance. The Tobit model was estimated using the maximum likelihood estimation in the Shazam econometrics package.

The estimated coefficients from a Tobit model are very difficult to interpret directly. The elasticity of the latent variable and the observed Y are used to assist in this interpretation (Whistler et al. 2001). The elasticity of the index variable Ii =X’i (ß/s) = X’i a. The percentage change in the index for a percentage change in Xk at the sample mean is given by

$$\varepsilon(I_i) - \hat{\beta}_k(\overline{X}_k / \overline{Y})$$

where s is the standard error of the estimate and a is the normalized coefficient. Similarly, the elasticity of E(Y) with respect to X is given as

$$\varepsilon(Y_i) - \hat{\beta}_k F(\overline{X}' \hat{\alpha})(\overline{X}_k / \overline{Y}_E)$$

where a^ =ß/s^ , YE is the expected value of Y at the mean values of all Xi,and F( ) is cumulative density function. The probability of adoption and the predicted level of adoption of improved pigeonpea varieties with respect to the changes in selected policy variables given the mean values of other variables are calculated using the cumulative standard normal distribution and the density functions as follows:

$$P(Y_i > 0) - F(X'\hat{\alpha}) = F(\hat{I}) \quad (4)$$

$$\hat{Y}_i = \hat{\sigma}\,\hat{I}_i F(\hat{I}) + \hat{\sigma}\, f(\hat{I}) \quad (5)$$

where F( ) is the cumulative standard normal distribution and f( ) is the standard normal density function.

Analytical methods to estimate social impacts

The social returns to investments in developing the fusarium-resistant pigeonpea varieties were estimated using the DREAM model (Wood et al. 2001). A more detailed description of the DREAM framework is given in Appendix 3. The model allows estimation of the magnitude and distribution of the economic benefits of agricultural research and development. The DREAM approach is based on the economic surplus method where research-induced supply shifts trigger a process of market-clearing adjustments in one or multiple markets affecting the flow of final benefits to producers and consumers (Alston et al. 1995). Certain basic data is needed for initial parameterization of the model to capture pre-adoption economic conditions in the areas. This would include region-specific data on quantity produced and consumed, producer and consumer prices, elasticities of supply and demand, and exogenous growth in supply and demand.

The base year market conditions used in the model are given in Table 9. The impact evaluation is carried out assuming three horizontal markets: Babati, rest of Tanzania (ROT), and rest of the world
(ROW). This implied an open economy that would require a global market clearing condition whereby total production across the three regions must equal total consumption. Price transmission elasticity is used to allow some degree of price transmissions between the three regions. DREAM allows technology spillovers from one region to the other. In this case, the technology adopted in Babati is assumed to generate some social benefits in the ROT, albeit delayed. This is specified in the spillover matrix. A conservative coefficient of 0.5 is used assuming that 50% of the cost-saving or productivity benefits realized in Babati would also be achieved in other pigeonpea-growing areas of the country with a lag of five years. Other areas may not be able to realize high benefits expected in parts of Babati attributable to good partnerships between research and development institutions as well as the private sector in the process of participatory on-farm evaluation, extension and market development for pigeonpea growers. The base year data shows that Babati produces roughly half of the pigeonpea in Tanzania. Since pigeonpea from Babati fetches a premium price, about 90% of the produce is marketed and directly exported primarily to Indian markets and to a lesser extent to European countries with significant Asian populations (Lo Monaco 2003). The analysis further assumes a planning horizon of 30 years with a 5% social rate of discount. Based on historical data (Silim, ICRISAT, personal communication 2004), the R&D process in developing and adapting the fusarium wilt resistant pigeonpea varieties in Babati is assumed to follow the following pattern: a research lag of 9 years, an adoption lag of 7 years with a logistic adoption curve, a maximum adoption level of 40% sustained over a period of 5 years, which will then take about 9 years for farmers to abandon the technology and shift to other new varieties. The costs for research,

Table 9. Initial market conditions used in the DREAM model.

Region	Quantity (1000 t)		Price	Elasticity		Price trans.	Exogenous growth (%/yr)		Growth of taxes/subsidy (%/yr)	
	Production	Consumption	US$/t	Supply	Demand	elast.	Supply	Demand	Supply	Demand
Babati	14.1	1.6	197	1	0.6	0.2	0.5	0.3	0.5	0.1
Rest of Tanzania	29.9	14.7	197	1	0.6	0.2	0.5	0.25	0.5	0.1
Rest of the World	2869.8	2897.5	325	1	0.6	0.25	0.25	0.2	0	0

Source: Compiled from different sources including FAOSTAT for national production and consumption and price data.

adaptation and extension of improved varieties were included. These were based on the actual and estimated expenditures of ICRISAT and partners for the entire planning horizon of 30 years.

There is a lack of information on the extent of fusarium infestation or the probability of infestation of uninfected fields in the district. Therefore, the adoption impacts are computed using two alternative yield gains, representing upper and lower bounds (Appendix 4). The expected yield gains are calculated with the assumption of low (10%) and high (30%) probabilities of infestation along with the existing low (25%) and high (50%) levels of infestation of pigeonpea farms. Since the yield level between local and improved varieties is similar in the absence of disease incidence, the average yield gain varies between 15% and 38% under the low and high levels of fusarium infestation, respectively. If the probability and/or actual level of infestation is higher than the estimated upper bounds, the yield difference and hence the economic impact of the new resistant varieties would be higher than what is estimated. Based on the evidence from survey data, we have assumed that the local varieties would incur about 50% yield loss in the event of disease incidence, while the comparative figure for resistant varieties is about 10% yield loss. Adoption of new varieties is assumed to generate a conservative 10% cost-saving per unit of output produced.

Results and discussion

The socioeconomic structure of production

Pigeonpea is an important crop in the farming systems of Babati. The crop is mainly planted in January as an intercrop with maize. In this system, maize matures early and is harvested usually in July while pigeonpea is harvested two months later in September. Majority of the farmers (85%) reported fusarium wilt in their fields. However, very few of them (about 6%) applied some control measures, mainly crop rotations. Farmers also reported problems related to different leaf diseases for the crop. About 79% of the respondents indicated that pod borer was a major pigeonpea field pest, but less than 10% of the farmers were able to control it using chemical sprays. Other field pests mentioned by the farmers in descending order of importance were aphids, pod suckers, blister beetle, termites, and pod flies.

Respondents reported that local varieties were more susceptible to fusarium wilt than the improved varieties (ICEAP 00040 and ICEAP 00053). While about 96% of local variety growers reported infestation by fusarium wilt, only 15% of the ICEAP 00040 growers and 13% of the ICEAP 00053 growers reported fusarium wilt attacks on the crop. Farmers reported grain losses due to fusarium wilt averaging about 57% for the local varieties (Babati white). However, the yield loss from fusarium was estimated at 4% for ICEAP 00053 and 3% for ICEAP 00040 during the 2002/03 cropping season. This showed that fusarium wilt was quite devastating for farmers growing local landraces when compared to the improved varieties. Given that farmers cultivate over 90% of the available farmland (Table 10), it is difficult to practise fallowing or crop rotation as measures of disease control. The only option available for smallholder farmers to control wilt in Babati is to adopt improved resistant varieties.

Table 10. Household assets.

Asset type	Nangara	Bagara	Singe	Managhat	Nakwa	Bonga	All (N=240)
Own farm size (ha)	1.0	1.5	1.3	1.3	1.4	1.3	1.3
Own cultivated land (ha)	0.9	1.3	1.2	1.2	1.4	1.2	1.2
Total cultivated (ha)	1.1	1.5	1.4	1.3	1.5	1.4	1.4
Livestock value (Tsh. '000)	377	487	443	375	350	369	400
No. of oxen	1.3	1.1	1.7	1.2	1.4	1.0	1.3
Total non livestock asset value (Tsh. '000)	102	75	147	92	65	94	96
Ownership of TV, radio or phone (%)	70	50	63	68	38	83	62

The socioeconomic characteristics of the sample households are given in Table 11. Most of the households interviewed during the survey had male household heads (82%). Majority of these household heads had 5–8 years of formal schooling (52.5%). Their average age was about 48 years and farming was their main occupation (94%). Since most of these household heads were farmers, majority of them resided on the farm (96%) and they provided full time farm labor (80%).

The average size of the surveyed households was about 6 members with a total workforce of about 2.5. Dependency ratio was found to be about 1.72 and this implied that for every active full time adult worker in the family, there were about 1.72 persons non-active family members. Alternatively, this means that each family worker is supporting about 1.72 non-working members in the household. The mean household farm size was about 1.3 ha of which about 93% is cultivated. This shows that average farm sizes are very small; the per capita cultivated land is about 0.22 ha, indicating a high level of population pressure and the need for intensification of agriculture to raise the productivity of land. The mean total operated land is slightly higher than own cultivated land because some households in-rented or borrowed some land from their relatives or neighbors (Table 10). About 14% of the total cultivated land was either in-rented or borrowed.2

About 90% of the surveyed households owned some livestock (cattle, shoats or poultry). The mean asset value of livestock wealth was about Tsh. 400,000. This was about 81% of the value of all the non-land assets owned by the households. About 39% of the surveyed households owned oxen for ploughing. The non-livestock assets such as agricultural implements, bicycles, radios, and other household goods constituted the remaining 19% of the household asset value, which were valued at about Tsh. 96,000 (Table 10). About 62% of the households either owned a radio, a TV set or a mobile phone, indicating a good level of access to information. The average asset wealth does not seem to vary substantially across villages.

Land borrowing occurs when a farmer obtains land without in-kind or cash payments (mainly from relatives) for seasonal cultivation. Such land will revert back to the owner after harvest unless a new arrangement is made for the next season.

Economics of new varieties

Production and productivity

The comparative productivity data for local and improved varieties is given in Table 12. The results show that yields varied significantly across villages and also between the two broad categories of varieties (improved varieties and local landraces). The average yield from the local varieties is about 425 kg/ha, but the comparative data for improved varieties is about 709 kg/ha (Table 12). Much of this gain is realized from the reduced productivity loss as a result of wilt resistant cultivars. Although the sample sizes are small to enable conclusive comparison between villages, yields of improved varieties seem to be highest in Bonga village followed by Singe and lowest in Nangara village. It may be useful to note that these are dry grain yields from intercropping with maize, the typical practice for smallholder pigeonpea production in the region.

Financial returns

Due to their high resistance to fusarium wilt, improved pigeonpea varieties are expected to provide higher economic returns to farmers than the local varieties. However, adoption of improved varieties may involve higher labor inputs for harvesting, etc, which imply higher production costs per unit area. The results from the comparative analysis of gross margins between the improved and local varieties are presented in Table 13. The average cost of production per ha is 23% higher for improved varieties. However, keeping output constant, the average variable costs of production are 26% lower for improved varieties. The main reason for the cost saving is the 67% higher yield for the improved varieties. A reflection of higher yields and lower costs per unit of output is higher overall net income to farmers from the adoption of improved varieties. On average, after accounting for the major variable costs of production, farmers adopting new varieties have an 80% higher net income per ha from pigeonpea production than non-adopting farmers.

Pigeonpea utilization and market participation

Most smallholder farmers in Tanzania are semi-subsistent producers of agricultural products which indicates that some of the produce is invariably used for home consumption while the surplus is marketed. For some products, market participation may be limited especially when markets are imperfect and unreliable for small producers. In such cases, farmers may choose self-sufficiency. However, there are relatively well-developed internal and export markets for pigeonpea in East Africa (Lo Monaco 2002). This implies that pigeonpea is a highly tradable commodity and small producers can earn substantial cash income from increased market-orientation of pigeonpea production. The pattern of utilization of pigeonpea production in Babati is shown in Table 14. About 98–100% of the farmers are engaged in pigeonpea production.

Table 14. Mean household pigeonpea utilization in kg (2002/03 harvest).

Varieties	Production (kg)	Sold (%)	Saved as seed (%)	Consumed (%)
All improved (N=240)	160	91	3	6
All local (N=240)	323	88	4	9
All pigeonpea (N=240)	483	89	3	8

In 2002/03, about 97% of the farmers were able to market some of their pigeonpea. On average, households marketed about 429 kg of grain, which represented about 89% of the total harvest.

Indicative of the market preference for large, white and uniform grains with good taste and cooking quality, farmers seemed to have marketed a slightly higher share of the improved pigeonpea than the local genotypes. However, a higher share of the produce from local types was used for home consumption. What was retained for home consumption is about 8% (38 kg) and for seed about 3% (15 kg) of the harvest. The high proportion of pigeonpea sold (89%) shows that pigeonpea is an important cash crop for smallholder farmers in the semi-arid areas of Tanzania. While maize is ranked by all the sample farmers as the most important food crop in the area, over 90% of the farmers ranked pigeonpea as the most important cash crop.3 If productivity can be increased significantly through the adoption of improved varieties and better management practices, a large marketable volume could be generated making a significant impact on poverty. For cash-constrained smallholder farmers, cash income generated from the crop can help them relax such constraints to adopt purchased inputs that are needed to intensify production. Since land is a very scarce resource in the area, intensification of production and diversification into high value crops is an essential step in poverty reduction.

In 2002/03 cropping year, 81% of the surveyed farmers grew local landraces (Babati White and Bangili types, the latter a mixture of local and improved varieties) and 96% of them sold some of the grain they harvested from these landraces. Similarly, improved pigeonpea varieties were grown by 25% of the surveyed farmers and 98% of these adopting farmers marketed some of the grain they harvested, indicating a positive impact of adoption on market participation and generating marketable surplus. A further analysis shows that adoption of improved varieties has indeed increased the level of marketed surplus of pigeonpeas (Table 15). The adopting farmers marketed about 716 kg per year while the non-adopting households marketed only 345 kg. A t-test shows that the average quantity marketed by the adopting group is significantly higher (P<1%) than the non-adopting group.

Table 15. The effect of adoption of improved varieties on marketed surplus of pigeonpeas (2002/03).

Household groups	Total production (kg)	Marketed surplus (kg)
Adopters (N=59)	792	716
Non-adopters (N=175)	395	345
Total (N=234)	495	439

3. Next to maize, households ranked pigeonpeas and beans as important food crops in that order. On the other hand, maize was ranked as the second most important cash crop followed by beans.

Adoption of improved varieties

Spread of improved varieties

The spread of adoption is measured in terms of the proportion of the sample farmers growing improved varieties of pigeonpea. About 98% of the surveyed farmers grew pigeonpea in 2002/03 cropping year. About 25% of the sample households reported that they had grown improved pigeonpea varieties. The analysis also showed that about 16% of the surveyed farmers grew only improved varieties, 9% grew both improved and local varieties, and 73% grew only local varieties. There were significant variations in adoption rates across the surveyed villages. Singe village had the highest adoption rate of 55% while Bagara and Nakwa villages had the lowest rates of about 8% each (Table 16). We find that these values are different from the initial estimates made by the key informants during the preparatory survey at the ward level, perhaps indicating how development partners at the local level would benefit in their planning activities if actual adoption data were made available. A substantial proportion of sample farmers (81%) reported that they had grown the local landraces 2002/03. Singe village had the lowest proportion of farmers growing the local landraces while Bagara village had the highest proportion. Several reasons were given as to why farmers continued to grow local varieties. These included socioeconomic constraints to adopt improved varieties, eg, unavailability of seeds and scarcity of land to try improved varieties. Another reason cited was the perceived low profitability or expected relative returns from improved varieties. Other factors considered to have contributed to low adoption of improved varieties are susceptibility to pod-borer and loss of yields due to shattering.

Table 16. Households (%) growing different pigeonpea varieties (2002/03 growing season).

Variety	Villages						
	Nangara	Bagara	Singe	Managhat	Nakwa	Bonga	All (N=240)
ICEAP 00040[1]	15	8	45	23	8	25	20
ICEAP 00053[1]	10	3	28	8	3	13	10
Babati White[1]	88	98	60	70	93	78	81
Bangili[2]	5	0	0	0	3	8	3
All improved varieties[1,3]	20	8	55	30	8	28	25
All local varieties[1]	88	98	60	70	93	80	81

1. Chi-square test of differences across villages was significant (P<0.05).
2. A mixture of improved and local varieties.
3. This also includes less-known varieties like ICEAP 00020 and ICEAP 00576-1 which are still being tested in the district.

The most widely adopted improved variety was ICEAP 00040 with about 20% of the surveyed farmers reported to have grown it in the 2002/03 season followed by ICEAP 00053 with 10% (Table 16). Singe village was leading in the adoption of both ICEAP 00040 and ICEAP 00053 varieties. Variations in adoption rates of these two most important improved varieties were statistically significant across the surveyed villages. However, this variation is likely to be a reflection of the level of promotion and access to seeds in the different villages. In the following cropping year ie, 2003/04, all the sample households grew pigeonpea. The level of adoption of improved varieties also increased from 25% during the previous year to about 34% during 2003/04, registering an increase of 9% (Tables 16 and 17). Also during this cropping year, about 23% of the sampled farmers grew only improved varieties, 11% grew both improved and local varieties, while about 66% grew only local varieties. There were also significant changes in the adoption levels across the villages with Singe village again having the highest adoption rate of 58% while Bagara village had the lowest adoption rate of about 10%. Bagara village, which also had the lowest adoption rate (8%) during the previous year, had only registered a 2% increase in adoption by 2003/04. Like in the previous year, ICEAP 00040 was the most widely adopted variety followed by ICEAP 00053 (Table 17). Consistent with the increase in the share of farmers adopting new varieties, the proportion of farmers growing local landraces dropped to 77% from 81% in the previous cropping year

(2002/03), indicating that as new varieties become available in the villages, farmers are likely to shift away from the local varieties.

Table 17. Households (%) growing pigeonpea (2003/04 growing season).

	Villages						
Variety	Nangara	Bagara	Singe	Managhat	Nakwa	Bonga	All (N=240)
ICEAP 00040[1]	18	10	43	30	25	35	27
ICEAP 00053[1]	15	3	33	25	3	15	15
Babati White[1]	85	95	58	58	85	78	76
Bangili	3	0	0	5	3	8	3
All improved varieties[1]	25	10	58	50	25	38	34
All local varieties[1]	85	95	58	60	85	80	77

1. Chi-square test of differences across villages was significant at p=0.05.

A substantial increase in the adoption rate of some of the villages could be attributed to the seed intervention in the village by Dodoma Transport Company, a private grain trading enterprise based in Arusha, Tanzania. ICRISAT provided seeds of improved varieties to this company which distributed seeds to farmers in some of the surveyed villages. The company also bought back the grains from the farmers. In an effort to encourage the company pay better prices to farmers, TechnoServe provided valuable market information to Dodoma Transport on attractive market opportunities for exporting pigeonpeas. This strategic alliance was very instrumental in enhancing the delivery of improved seeds to farmers and in providing reliable market outlets to their produce.

The 25% and 34% adoption levels in the surveyed villages does not, however, imply a similar level of adoption at the district level mainly because improved varieties have not been promoted in all the 21 wards of the district. The pre-survey assessment reported in Table 7 has shown that improved varieties are adopted mainly in 4 of the 21 wards. As such, the conservative estimate for the district-wide adoption level is likely to be approximately 5% in 2002/03 and about 8% in 2003/04[4].4 While the high levels of uptake in the adopting villages and the high profitability of the new technologies indicates the promising potentials for increasing adoption of new varieties in the district, the low district level adoption rate at this stage indicates the need for a significant effort in technology promotion and making the seeds available and accessible to farmers to boost adoption in the district.

Adoption intensity

The adoption intensity measures the depth or extent of adoption expressed in terms of the proportion of the total cultivated area or pigeonpea growing area allotted to improved varieties. The results are presented in Table 18, which also summarizes the adoption spread discussed above. The results discussed earlier have shown that households cultivate about 93% (1.2 ha) of the total owned farmland. Including land rentals, the mean cultivated land increases to about 1.40 ha, 75% (1.05 ha) of which was under the mixed maize-pigeonpea production in 2002/03. This increased to about 81% (1.13 ha) in the following cropping year. The adoption intensity would then need to estimate the share of this pigeonpea area, which is allocated to new varieties.

[4] This assumes that the varieties are not adopted in the 17 wards and is estimated based on the proportion of the total number of adopting households in the four adopting wards in relation to the total number of farmers in the district. Despite the low levels, the number of adopting farmers in the 17 wards might be quite significant, making this estimate very conservative.

Table 18. Adoption levels and area under different pigeonpea varieties.

Variety	Growers (%)		Average area (ha)	
	2002/03	2003/04	2002/03	2003/04
ICEAP 00040	20	27	0.17	0.25
ICEAP 00053	10	15	0.07	0.10
Babati White	81	76	0.79	0.76
Bangili	3	3	0.01	0.01
All improved varieties	25	34	0.25	0.36
All local varieties	81	77	0.80	0.77
All pigeonpea varieties	98	100	1.05	1.14

Note: N = 240

The results for adoption spread and intensity summarized in Table 18 are strikingly very similar. About 24% (0.25 ha) of the total area under pigeonpea in 2002/03 was planted with improved pigeonpea varieties. This share increased to about 32% (0.36 ha) in the following cropping year (2003/04), indicating an 8% increase in the intensity of adoption of pigeonpea varieties in the surveyed villages. With more promotion and relaxing of the adoption constraints (discussed below), the potential to increase the spread and intensity of adoption in the district and beyond is high.

Determinants of variety adoption

Farmer adoption of a given cultivar is usually a process, which passes through several stages. The first step is for the farmers to get to know the variety. Upon an initial assessment of the expected returns from the technology, the farmer may then decide to try out the technology. Depending on the performance of the technology, the evaluation by the farmer may take several growing seasons. If the technology is found attractive in terms of either increased profitability and/or reduced risk for risk-averse farmers, and if socioeconomic constraints do not limit the decision process, the farmer will decide to switch from the old to the new technology. Otherwise, the farmer will decide to reject the technology. To gain insights about the level of adoption and the underlying factors that constrain or facilitate the adoption process, it is useful to examine the factors that determine technology uptake. Such ex-post insights are important to both researchers and policy makers. The researcher would gain useful feedback on the level of uptake of the technology by the clientele and the attributes of the technology that conditioned the level of adoption. This can be useful in designing and developing well-suited technologies that meet the needs of the target population. Policy makers can use such information to reform the policies that constrain technology uptake or formulate and implement new instruments that hasten and support the adoption process.

Variables in the Tobit model and hypothesized effects

Small farmers in developing countries are farm households who are engaged in both production and consumption of the same products. Smallholder farmers in many rural areas are semi-subsistent producers and consumers partially integrated into imperfect rural markets. The theory of farm household economics has demonstrated that when rural input and output markets are imperfect, production and technology adoption decisions are influenced by the level of poverty and asset ownership of the farmer (Singh et al. 1986; de Janvry et al. 1991). This implies that assuming imperfections in labor, credit, land and other input markets, household characteristics and assets including family labor force and livestock and non-livestock asset endowments would be important factors in technology adoption decisions. Besides, perceptions about the technology, access to information, and improved seeds are critical factors in technology choice decisions. Accordingly, 15 variables – capturing household and farm characteristics, assets, technology perception, access to information and improved seeds – were included in the model (Table 19). The hypothesized relationships were also indicated. Economic theory does not suggest any clear hypothesis on the effect of demographic factors such as age and gender.

Hence, the anticipated signs are indeterminate. When labor markets are imperfect or credit needed for hiring workers is constrained, education of the farm manager increases the ability to access and process information. Education also increases skills and may increase the relative returns to other more skill-intensive activities both on- and off-farm. This means that it is also difficult to anticipate a definite sign on the likely effect of education.

However, under the imperfect market assumption, higher per capita availability of family resources such as land, labor, traction power and assets – both livestock and non-livestock – are expected to have a positive influence on adoption. In addition, pigeonpea is grown mainly as an intercrop with maize and sometimes with maize and beans. An increase in the share of maize and beans in the total area may therefore be associated with the adoption of new varieties. However, beans can also be a substitute for pigeonpea, indicating that an increase in the area share of beans may reduce the adoption of pigeonpea. Knowledge about improved varieties and ownership of radio and TV sets for accessing new information are expected to increase adoption.

Other variables such as farmer perception of low relative returns from switching to the new varieties are expected to negatively affect adoption directly. Similarly, the existence of socioeconomic constraints for adoption (not captured by the asset variables) even when the technology is perceived as relatively attractive is also likely to reduce the probability and/or intensity of adoption. Improved access to new seeds from formal seed supplies such as extension services and participatory on-farm trials are expected to increase the likelihood and level of variety adoption.

Table 19. Variables included in the Tobit model and hypothesized relationships.

			Adopters (N=82)		Non adopters (N=158)	
Variable	Description	Hypothesis	Mean	Std. Dev.	Mean	Std. Dev.
Pigeonpea share	Share of improved pigeonpea in total cultivated area	Dependent variable	0.719	0.298	0.000	0.000
Sex	Sex of the household head (0 = Female, 1 = Male)	+/-	0.878	0.329	0.797	0.403
Age	Age of the household head (Years)	+/-	47.38	12.981	48.41	15.708
Education	Education level of the household head (0 = No formal education, 1 = Adult education, 2 = 1–4 years, 3 = 5–8 years, 4 = Secondary, 5 = Post secondary)	+/-	2.35	1.211	2.05	1.310
Farm size	Per capita own farm	+	0.91	1.485	0.53	0.381
Traction power	Per capita oxen for ploughing	+	0.29	0.627	0.21	0.370
Workforce	Total household workforce	+	2.48	1.290	2.47	1.361
Maize share	Maize share in total cultivated area	+	0.739	0.282	0.842	0.247
Bean share	Beans share in total cultivated area	+/-	0.180	0.218	0.130	0.231
Livestock wealth (1000 Tsh)	Per capita total livestock value excluding oxen for ploughing	+/-	50.97	52.15	39.21	51.07
Non-livestock wealth (1000 Tsh)	Per capita total non livestock value excluding TV, radio and mobile phone	+	16.23	22.13	10.84	14.37
Variety knowledge	Knowledge of improved varieties (1 = Knows at least one variety, 0 = Don't know any variety)	+	0.988	0.110	0.475	0.501
Ownership of ICT	Television, radio and mobile phone ownership (1 = Owns TV, radio and or mobile phone, 0 = Doesn't own)	+	0.732	0.446	0.557	0.498
Profitability perception	Perception of profitability of new varieties (1 = poor profitability, 0 = good profitability)	-	0.049	0.217	0.082	0.276
Financial constraints	Financial constraints to adoption (1 = Yes, 0 = Otherwise)	-	0.012	0.110	0.323	0.469
Access to seed	Access to improved seed proxied in terms of source of seed (0 = Seed non-accessible 1 = Access from informal sources 2 = Access from formal sources)	+	1.122	0.365	0.000	0.000

Regression results

The Tobit model results are given in Table 20. Seven variables were found to have significant effects in explaining the level of adoption of improved varieties in the district; sex of the household head, area share of maize, education of the household head, knowledge about varieties, perceived profitability of the varieties, expressed socioeconomic constraints, and the level of access to new seeds. Keeping other model variables constant, households with female heads seem to be less likely to adopt the new varieties (P<0.1). The index of adoption is 0.93% higher for male household heads compared to female household heads. The expected value of the area share under improved varieties is also 1.02% higher for households with male households. This may reflect the special difficulties that women farmers face in the area, which are not captured fully by the variables included in the regression. This may also be a reflection of imperfections in labor markets. The other interesting result is the effect of education. Data was not available on the level of education of individual members. Hence, the level of education of the head, measured in terms of ordinal categorical values, was used. The results show that, keeping other model variables constant, adoption of pigeonpea varieties decreases as the level of education increases (P<0.01). This may reflect that those better educated farmers with higher skills are more likely to find other alternative sources of income, with higher relative returns to family resources (eg, off-farm employment). It may be useful to further explore this relationship in the future and examine how agricultural incomes from dryland pulses relate to household education. As expected, the adoption level increases with an increase in the share of land allocated to maize (P<0.1) showing a strong complementarity in the production of two crops grown as intercrops. The elasticities at the means indicate that a 10% increase in the share of maize would increase the index of adoption by 8.4% and the expected area under the new varieties by 9.5%.

Table 20. The Tobit model regression results.

Variable	Normalized coefficient	Asymptotic standard error	T-ratio	Regression coefficient	Elasticity of index	Elasticity of E (Y)
Sex	0.596	0.342	1.743	0.222	0.903	0.846
Age	-0.010	0.009	-1.038	-0.004	-0.699	-0.794
Education	-0.413	0.149	-2.772	-0.154	-0.875	-0.994
Maize share	0.687	0.397	1.729	0.255	0.838	0.952
Beans share	0.112	0.477	0.234	0.042	0.025	0.028
Farm size	0.111	0.096	1.158	0.041	0.110	0.125
Traction power	-0.360	0.266	-1.353	-0.134	-0.129	-0.146
Livestock wealth	0.000	0.000	0.949	0.000	0.122	0.138
Non-livestock wealth	0.000	0.000	0.589	0.000	0.076	0.086
Ownership of ICT	0.234	0.252	0.928	0.087	0.354	0.403
Family work force	-0.016	0.086	-0.184	-0.006	-0.059	-0.068
Variety knowledge	2.503	0.476	5.255	0.931	3.788	4.302
Profitability perception	-1.499	0.415	-3.607	-0.558	-2.269	-2.577
Financial constraints	-1.925	0.450	-4.280	-0.716	-2.914	-3.309
Access to improved seeds	1.619	0.240	6.734	0.602	0.939	1.067
Constant	-2.708	0.868	-3.118	-1.007		

Log-likelihood function = –53.86. The predicted probability of Y > 0 given average values of X = 0.23. The observed frequency of Y > 0 = 0.342. E(Y) at mean values of all X = 0.0498.

Farmer knowledge about the improved varieties is also positively correlated with adoption (P<0.01). At the mean values of the other variables, farmers who have some knowledge about the popular varieties (ICEAP 00040 and/or ICEAP 00053) are likely to have a 3.8% higher adoption index than those who do not know about the varieties. The expected value of the area share under improved varieties at the mean values is also 4.3% higher for those who are aware of the improved varieties. This shows the importance of sensitizing farmers about the existence of alternative technologies. This is the first key step for the farmer in making an important technology choice decision.

Once the farmer is aware of the availability of the technology, the next step is to evaluate the relative returns vis-à-vis the local options. As expected, farmer perceptions about the profitability of the varieties had a significant influence on adoption (P<0.01). On average, farmers who perceive the improved varieties as non-profitable or less profitable relative to the traditional options had a 2.26% lower adoption index compared to those who perceive them to be relatively economically attractive. At the means, the expected value of the area share under improved varieties is also 2.58% lower for farmers who perceive the varieties as less profitable. Farmers may not however adopt a technology even when they perceive them to be economically viable and more profitable. There could be a host of factors that constrain uptake, including variables such as poverty (cash constraints) and lack of access to new seeds. The expressed cash constraint by the farmers had a significant negative impact on the adoption of new varieties (P<0.01). At the mean values of other variables, cash-constrained farmers have a 2.9% lower adoption index compared to those who did not express such constraints as limiting factors for adoption. The expected level of adoption of improved varieties is also 3.3% lower for cash-constrained farmers. Similarly, improved availability of seed through alternative channels was found to have a significant positive effect on adoption (P<0.01). At the means for all the variables, a 10% increase in the availability of new seeds through various seed supply systems would increase the index of adoption by 6% and the expected value of area under improved varieties by 1.06%, showing an elastic responsiveness to relaxing the seed availability constraint to the farmer.

Policy analysis

The Tobit regression has shown the importance of three major policy variables; improving returns to technology adoption, relaxing economic constraints and improving access to new seeds in promoting the adoption of improved pigeonpea varieties in Babati. In order to further explore the relative gains from implementing a mix of these policies, a simulation experiment was done using the estimated regression equation. The probability of adoption of improved varieties and the intensity of adoption measured in terms of the predicted area share under improved varieties were estimated at the average values of the variables using equation (4) and (5), respectively. Access to improved seed was measured at three qualitative ordinal categories: very good, good and poor. This was combined with expressed views of farmers on variety profitability and cash constraints for adoption. The results given in Table 21 show that when farmers perceive the varieties to be economically attractive, access to new seed is very good and farmers do not face cash constraints in buying the seeds. The probability of adoption of the varieties is close to 100% and the predicted area share under the improved varieties would be about 89.5%. Under the same conditions, if access to seeds goes down progressively to good or bad, the adoption probability drops to 78% and 20%, while the predicted area under improved varieties declines to 34% and 4% of the cultivated area, respectively. This shows the critical role that seed supply systems play in boosting technology uptake when the technology is economically viable and economic constraints to adoption are non-binding. On the

Table 21. The effect of selected policy variables on the probability and level of adoption.

Scenarios	Access to seed	Profitability of technology	Economic constraints	Adoption index	Probability of adoption	Area share under improved pigeonpea
I	Very good	Good	No	2.403	0.992	0.895
II	Good			0.784	0.784	0.338
III	Bad			-0.835	0.202	0.042
IV	Very good	Good	Yes	0.478	0.684	0.254
V	Good			-1.141	0.127	0.024
VI	Bad			-2.760	0.003	0.000
VII	Very good	Poor	Yes	-1.021	0.154	0.030
VIII	Good			-2.640	0.004	0.000
IX	Bad			-4.258	0.000	0.000

other hand, the presence of cash constraints (scenarios IV–VI) decreases the probability of adoption progressively to 68%, 13% and 0.03%, a significant fall compared to scenarios I-III. As most smallholder farmers are cash constrained to adopt viable technological options, these scenarios are perhaps most realistic under the prevailing conditions in Babati. For example, if the level of access to new seeds is 'good' and farmers are cash-constrained, the probability of adoption will just be about 13% and the predicted area share of adoption about 2.4%.

The scenarios VII-IX simulate the situation where the economic viability of the technology is poor and the target farmers are cash-constrained. This is the worst situation for technology adoption. The results show that even with high levels of access to seeds the probability of adopting the varieties is very low. Under such conditions, the pigeonpea varieties will have no credible chance of being adopted by farmers regardless of the effort in improving the availability of seeds at the local level. In the first instance the technologies need to be economically attractive to farmers when grown under the farmer's growing conditions; second, along with efforts to increase the supply of improved seeds, the cash constraints that stifle technology uptake need to be relaxed so as to stimulate increased adoption.

Social impacts

In this section we present results from the DREAM model which was used to evaluate the social returns to investments in developing the fusarium wilt resistant pigeonpea varieties. The results are presented for two scenarios, representing upper and lower bounds on the expected yield gains from adoption of fusarium-resistant improved varieties.

The results for these two scenarios are given in Table 22. Even under the low expected yield gain scenario, the R&D investments in developing the fusarium wilt resistant varieties would generate significant benefits to small farmers and consumers both in Babati and through spillovers to other parts of Tanzania. The lion's share of the benefits accrues to the smallholder farmers who benefit from increased productivity and lower per unit costs of production. The government also benefits from increased tax revenues received from both producers and consumers. Considering the benefits and costs in Tanzania alone, the net present value (NPV) of the investment is about US$2.368 million. Even if one assumes no spillover benefits, the R&D investment would have generated sufficient social net benefits from Babati alone. This can be seen from the NPV value of US$1.48 million for Babati. The overall benefit-cost ratios are about 6.72 and 4.22 in Babati and ROT, respectively. The IRR from the investment is 26.7%.

Table 22. Returns to research and development (R&D) investments.

Region	Present value (PV) of R and D benefits (1000 US$)				PV of costs (1000 US$)	(B-C)	B/C	IRR (%)
	Producers	Consumers	Government	Total				
Expected yield gain of 15%								
Babati	1726	1.5	9.7	1737.3	258.2	1479	6.72	25.3
Rest of Tanzania	1143.7	14.1	6.8	1164.7	275.5	889.1	4.22	39.3
Total NPV	**2869.7**	**15.6**	**16.5**	**2902**	**533.7**	**2368.1**	**5.5**	**26.7**
Expected yield gain of 38%								
Babati	3363.9	2.8	18.3	3385.1	258.2	3126.8	13.1	33.1
Rest of Tanzania	2173.1	26.3	12.8	2212.4	275.5	1936.8	8.02	57.7
Total NPV	**5537**	**29.1**	**31.1**	**5597.5**	**533.7**	**5063.6**	**10.61**	**34.60**

If the expected yield benefits from developing the fusarium wilt resistant varieties are as high as 38%, the social benefits basically double. The NPV of the investment increases to US$5.14 million.

The benefit-cost ratio also increases to 10.61, while the IRR jumps to 34.6%. In sum, this analysis shows that the R&D investments in developing fusarium wilt resistant pigeonpea varieties in Tanzania have generated significant economic benefits to society. These benefits are likely to have significant impacts on food, nutrition and poverty in the pigeonpea growing areas of Tanzania. This study has not explored such impacts at this stage of the adoption process. Since pigeonpea is a nitrogen-fixing legume, it may also generate significant environmental and sustainability benefits that improve ecosystem health if area under the crop expands beyond what was grown under traditional varieties. In addition to exploring the poverty and food security related benefits along with the distribution of these benefits to the different segments of the society, a more comprehensive ex-post impact assessment would require careful evaluation of the economic and environmental impacts of the interventions using appropriate methodologies (Shiferaw et al. 2004).

Summary and policy implications

Pigeonpea is an important crop in the smallholder production systems of several countries in eastern and southern Africa, mainly Tanzania, Uganda, Kenya, Malawi and Mozambique. It is a drought-tolerant crop grown in many semi-arid and drought prone areas in the region. It is a nutritious legume, which is a cheap source of protein for many poor families. It is also a nitrogen-fixing legume, which has the potential to enrich soil fertility, and can be grown by cash-constrained farmers without the application of fertilizers. It is commonly grown as an intercrop with cereals (maize, sorghum and finger millet) in densely cultivated areas where land is scarce. This allows farmers to earn incomes from utilization of the residual moisture after the cereal crop has been harvested. In Tanzania, it is one of the most important legumes produced by smallholder farmers as a cash crop. Despite these potentials, the productivity of pigeonpea in Tanzania was highly limited due to a devastating disease, fusarium wilt caused by soil-borne fungus. The disease is very difficult to control once infestation has occurred and causes up to 50% productivity loss when susceptible varieties are grown. The disease can spread into new areas through infested seeds or through farm equipment and other means that transfer the fungus to new areas.

ICRISAT had long recognized the need for controlling the disease to improve the well-being of smallholder farmers in the region. Since the early 1990s, a collaborative research program was initiated in the region, which brought together a broad network of partners including farmers, the national research systems and private sector commercial enterprises. This has proven to be successful in developing several varieties preferred by farmers as well as the market and has made significant contributions in shortening the research lag in developing interventions with a high probability of adoption. The fusarium wilt resistant varieties were initially tested on-station and later evaluated on-farm in Babati district of Tanzania. This study investigates the spread and intensity of adoption of improved varieties in this district as well as the policy-relevant factors that conditions technology choice and adoption decisions by farmers. A more comprehensive analysis of the socioeconomic impacts of the technology was also carried out using IFPRI's DREAM model for technology evaluation and impact assessment.

The current level of adoption of the technologies is limited to the few locations in Babati where seed supply and extension efforts have been focused. The spread of adoption in these areas has reached about 34% of the farmers while the intensity of adoption is about 30% of the cultivated areas. The survey data shows that economic benefits to adopting farmers might be as high as 80% higher than the non-adopting farmers, indicating a high level of return on investment when production costs between the local and improved varieties are similar. If the adoption benefits are as high as estimated here, the low level of adoption at the district level indicates the untapped opportunities that exist for enhancing farmer incomes through institutional arrangements that improve the access and utilization of new varieties and provide market outlets for producers. The analysis has also shown that access to seeds from informal channels and farmer-to-farmer technology transfer is not going to be sufficient to spread the varieties widely. More effort in terms of strengthening the institutional architecture for effective technology dissemination is therefore needed to accelerate the adoption process in other parts of the district. The analysis using Tobit regression has helped to identify the most important policy variables to enhance technology uptake. It should be noted that relative economic profitability is necessary but not sufficient for adoption of new technologies. Risk considerations and other socioeconomic factors can still limit technology uptake and adaptation. Awareness campaigns, especially for the two varieties (ICEAP 00040 and ICEAP 00053), combined with improved availability of new seeds to farmers and provision of credit for cash-constrained farmers to buy the new seeds would provide the most promising policy mix to accelerate and promote adoption of the new varieties. Efforts to enhance market access to producers and better prices for the crop will also increase the relative profitability and encourage adoption. The lessons from the effective partnerships between private and public sector institutions along with ICRISAT in Babati in the process of on-farm variety evaluation, extension and market development attests to these results.

If these investments are made to enhance adoption in the district and to extend the benefits to the rest of Tanzania, the economic benefits to smallholder producers and consumers in Tanzania would by far outweigh the costs even with very modest yield gains from adoption of new varieties. The rate of return from the R&D investments by the ICRISAT-led partnership is estimated to be around 26% to 34% for the low and high bounds assumed about the expected yield gains from adoption of fusarium-resistant varieties. The social gains would be higher if one accounts for the drought tolerance as well as the sustainability and ecosystem health benefits resulting from controlling the disease and increased adoption of legumes in cereal-based systems. The associated poverty reduction as well as the food and nutritional security benefits to the rural poor need to be investigated in the future.

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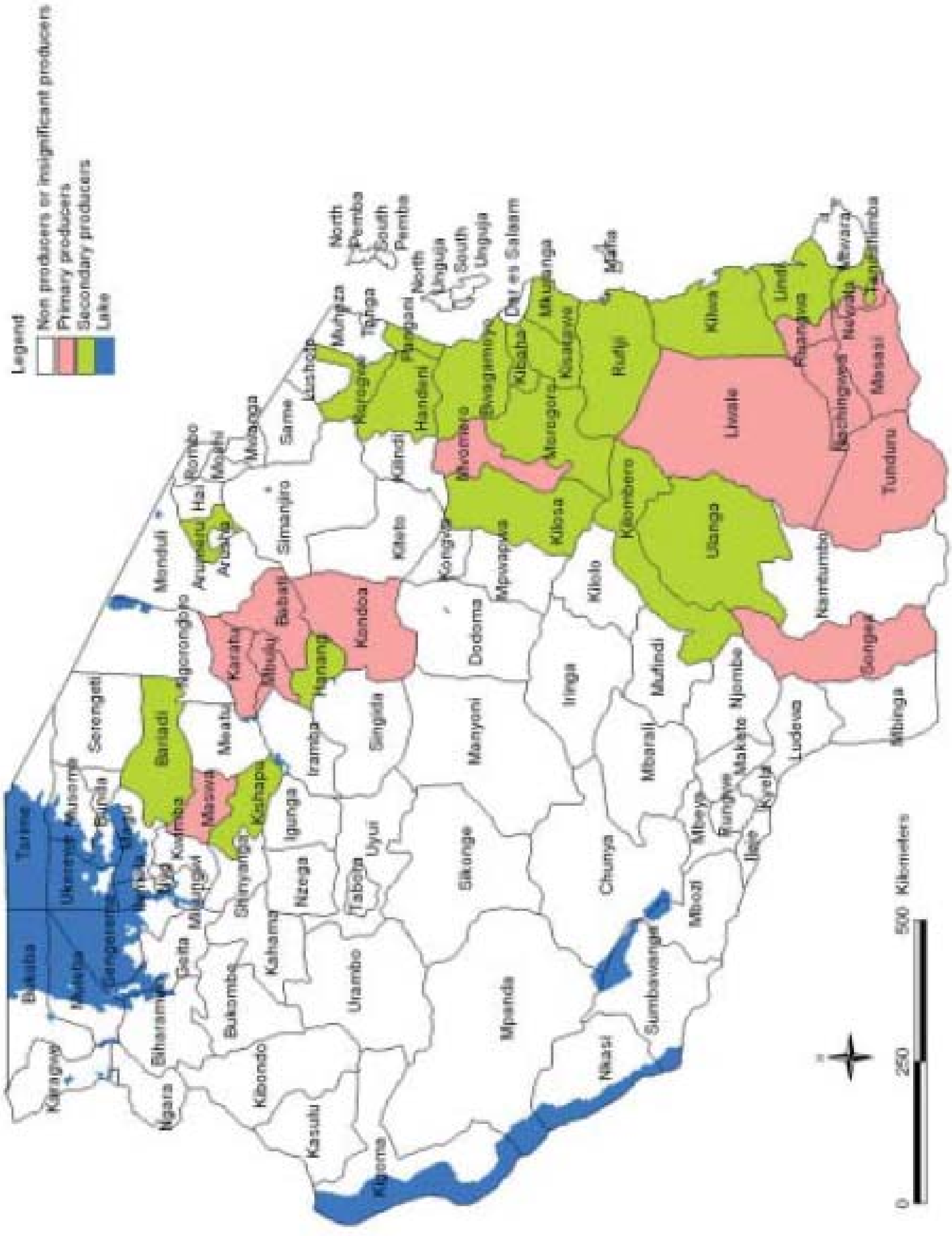
Appendixes

Appendix 1. Pigeonpea growing districts in Tanzania.



Appendix 2. Biological and market related traits of improved pigeonpea varieties tested in Tanzania.

Trait	ICEAP 00040	ICEAP 00053	ICEAP 00020	ICEAP 00576-1	ICEAP 00068	ICPL 87091	Babati White	Morogoro line
Released	Yes	Pending	No	No	Yes	Yes	Local	Local
Year of release	2002	-	-	-	2003	1999	-	-
Release name	Mali	-	-	-	Tumia	Komboa	-	-
Maturity period (LD, MD or SD)	LD	LD	LD	LD	MD	SD	LD	MD
Yield potential (t/ha)	3.2	2.3	3.1	2.6	3.5	2.5	2.5	2.0
Grain color	White	White	White	White-cream	White-cream	Cream	White	Cream
Grain size	Large	Large	Large	Large	Very large	Small	Medium to large	Medium to large
Uniformity in maturity	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform	Not uniform	Not uniform
Fusarium wilt	Very resistant	Resistant	Resistant	Resistant	Resistant	Susceptible	Very susceptible	Very susceptible
Other diseases	Resistant	Partially resistant	Moderate	Moderate	Resistant	Low	-	-
Pests	Partially resistant	Moderate	Moderate	Moderate	Moderate	Extremely susceptible	Susceptible	Very susceptible
Taste	Excellent	Excellent	Excellent	Excellent	Excellent	Good	Good	Good
Cooking quality	Excellent	Excellent	Excellent	Excellent	Excellent	Not good (takes too long)	Bad	Good

Source: Silim and Gwata, ICRISAT, personal communication 2004.

Appendix 3. The DREAM model.

DREAM stands for Dynamic Research EvAluation for Management (Wood et al. 2000). DREAM is designed to measure economic returns to commodity-oriented research under a range of market conditions, allowing price and technology spillover effects among regions as a consequence of the adoption of productivity-enhancing technologies or practices in an innovating region. Linear equations are used to represent supply and demand in each region with market clearing enforced by a set of quantity identities and price identities. It is a single-commodity model without explicit representation of cross-commodity substitution effects in production and consumption — although, of course, these aspects are represented implicitly by the elasticities of supply and demand for the commodity being modeled. In particular, DREAM assumes all commodities are tradable between regions (although a spectrum of possibilities from free trade to autarky can be represented). The supply, demand and market equilibrium are defined in terms of border prices which will differ from prices received by farmers (or paid by consumers) because of costs of transportation, transactions, product transformation, and so on that are incurred within regions between the farm and border. The linearity of DREAM model is good for small equilibrium displacements such as those single-digit percentage shifts of supply or demand, which is common for most of the agricultural technology changes. Alston and Wohlgenant (1990) showed that changes in estimated research benefits from comparatively small equilibrium shifts of linear models provides a reasonable approximation of the same shifts (in this case parallel shifts) with various other functional forms. Small shifts have the added virtue that the cross-commodity and general equilibrium effects are likely to be small (and effectively represented within the partial equilibrium model), and that the total research benefits will not depend significantly on the particular elasticity values used (although the distribution of those benefits between producers and consumers will). Even with all these simplifications, which make the DREAM model tractable, significant effort is needed to parameterize and use the model to simulate market outcomes under various scenarios (Alston et al. 1995; Alston et al. 2000).

The primary parameterization of the model's supply and demand equations is based upon a set of demand and supply quantities, prices, elasticities in a defined "base" period. DREAM also allows for underlying growth of supply and demand to be built into the model to project a stream of shifting supply and demand curves into the future that we can solve for a stream of equilibrium prices and quantities, in the "without research" scenario. These "without research" outcomes can be compared with the "with research" outcomes, which are obtained by simulating a stream of displaced supply curves, incorporating research-induced supply shifts. The research-induced supply shifts are defined by combining an assumption about a maximum percentage research-induced supply shift under 100 percent adoption of the technology in the base year, with an adoption profile, representing the pattern of adoption of the technology over time. Finally, measures of producer and consumer surplus are computed and compared between the "with research" and "without research" scenarios, and these are discounted back to the base year to compute the present values of benefits. In the case that we know the costs of the research that are responsible for the supply shift being modeled, DREAM will compute a net present value or IRR.

DREAM has been developed into a computer software package (Wood et al. 2000). It has menu-driven, user-friendly interface which hides the complex computation to allow user to focus on methodology, data collection and policy interpretation. DREAM explicitly includes four market types: horizontal multi-market, open economy, closed economy, and three-level vertical market. The region in DREAM can be any spatial unit, either geopolitical region such as country, province, county or agroecological zones such as humid and temperate zone, tropics and arid zone. DREAM allows users to specify technology shifts, adoption, elasticities, and exogenous growth rates that change over the simulation period. It provides a framework for exploring various kinds of policy, technology, extension and trade issues (Alston et al. 2000).

Appendix 4. Estimation of expected yield benefits from adoption of fusarium-resistant varieties in Babati district.

	Low infestation	High infestation	Remarks and assumptions
Local fusarium-susceptible varieties			
Yield on fusarium-free plots (t/ha)	2.536	2.536	80% of the yield level attained on-station
Yield on fusarium-infested plots (t/ha)	1.268	1.268	50% yield loss
Probability of fusarium infestation	**0.1**	**0.3**	
Probability of non-infestation	0.9	0.7	
Share of already infested plots	0.25	0.5	
Share of non-infested plots	0.75	0.5	
Expected yield on fusarium-infestible plots (t/ha)	2.4092	2.1556	
Average expected yields in the district with local varieties	**2.12**	**1.71**	
Improved fusarium-resistant varieties			
Yield on fusarium-free plots (t/ha)	2.536	2.536	80% of the yield level attained on-station
Yield on fusarium-infested plots (t/ha)	2.2824	2.2824	10% yield loss
Probability of fusarium infestation	**0.1**	**0.3**	
Probability of non-infestation	0.9	0.7	
Share of already infested plots	0.25	0.5	
Share of non-infested plots	0.75	0.5	
Expected yield on fusarium infestible plots (t/ha)	2.51064	2.45992	
Average expected yields in the district with resistant varieties	**2.45**	**2.37**	
Yield gains due to control of fusarium wilt (t/ha)	0.33	0.66	
Yield gains (%)	**15.52**	**38.52**	