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The Potential Returns to Oilseeds Research in Uganda: The Case of Groundnuts and Sesame

by

Rita Laker-Ojok

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1. INTRODUCTION

The study which follows is an ex-ante analysis of expected returns to investment in agricultural research on groundnuts and sesame in Uganda. Studies have shown that it generally takes a minimum of six to ten years for new technologies to begin to have an impact on agricultural production practices. In the case of Uganda, Michigan State University was asked to measure the impact of a program which only began the process of rehabilitating the collapsed national agricultural research system in 1985 and began support for commodity research on groundnuts and sesame as recently as 1989 and 1991. As a result, the assessment which follows relies upon the projection of expected future benefits. While every effort has been taken to make reasonable projections based on the limited available information, no prediction of the future can ever be made with certainty. For this reason, the results should be considered indicative at best. Follow-up research will be required to test the ultimate validity of the assumptions upon which it has been based.

1.1. Background

This assessment of the projected rate of return to groundnut and sesame research in Uganda was carried out as the second step of a longer effort to assess the impact of agricultural research in Uganda. The first step involved a study of maize, soybean, and sunflower research. The results of that assessment were reported in "The Rate of Return to Agricultural Research in Uganda: The Case of Oilseeds and Maize."

The Uganda case study was conducted as one of seven case studies under the Agricultural Research Impact Assessment add-on to the Michigan State University "Food Security in Africa" cooperative agreement with USAID.

The research was conducted with the assistance of three collaborating institutions in Uganda: (1) Makerere University, Faculty of Agriculture and Forestry (MUFAF); (2) the Ministry of Agriculture, Animal Industries and Fisheries (MOAAIF); and (3) the Manpower for Agricultural Development Project (MFAD) of the Uganda AID Mission, under whose auspices additional local currency resources were made available for transportation, enumerator salaries, and travel allowances. MFAD also provided access to administration and communications facilities.

The research design, data collection, and analysis are the result of a joint effort between the author, who is the MSU in-country researcher, and three Ugandan consultants: Mr. Bernard Bashaasha, Ms. Elizabeth Balirwa, and Mr. Godfrey Turiho-Habwe. Both the Ministry and the faculty granted release time to staff in order to allow them to participate fully in the research effort.

1.2. Objectives of the Research

The objectives of this component of the study are

(1) to determine the potential returns to future investment in research on the major traditional oilseeds in Uganda, namely groundnut and sesame;

(2) to compare these results with the projected returns from maize, soybean, and sunflower research;

(3) to discuss the key institutional and policy factors which influence the effectiveness of the agricultural research and technology transfer system and hence the return to research in Uganda; and

(4) to make preliminary recommendations concerning how rate of return analysis might be used to establish priorities for allocating agricultural research resources among commodities in Uganda, and to analyze the implications for complementary investment in improving the institutional and policy environment.

1.3. The Rate of Return as a Measure of Project Worth

When new technology is adopted, the increased productivity of the agricultural sector benefits a wide range of actors in society. Producers benefit from lower production costs and increased returns to limiting factors of production (land, labor, or capital). Consumers (including farm households) benefit from increased product availability, improved product quality, and lower prices. The nation benefits from the improved health and productivity of its citizens as well as broader economic linkages to the industrial sector. If agricultural research were only conducted by private firms, research investment would be limited to those technologies for which the firm expected to be able to capture sufficient returns to generate a profit on its investment. The firm's private marginal cost would be equated to private marginal benefit rather than to marginal social benefit, resulting in a sub-optimal level of investment.

Benefit-cost analysis is often employed to evaluate decisions regarding the appropriate level and distribution of public sector investments in agricultural research. The rate of return (ROR) is the measure of project worth most commonly used in this evaluation.[1] The ROR is a single number which summarizes the time pattern and the relative sizes of the cost and the benefit streams resulting from the project. The ROR is comparable to the rate of bank interest which the investment would have to earn to achieve the same net returns as the research project. Once the ROR has been calculated, it can be compared to the prevailing interest rate or some other measure of the opportunity cost of capital to determine the relative attractiveness of the

[1] The advantages and disadvantages of various alternative measures of project worth are discussed in detail by Gittinger (1982).

investment. If the ROR exceeds the cost of capital then the project is considered economically successful (Oehmke and Crawford 1993).

A number of different methods have been used to calculate the rate of return to agricultural research. These include the index number approach, the production function method, mathematical programming and simulation studies.[2] Given the limited data available in Uganda, the benefit-cost approach is the one selected for the ROR study.

[2] For a more detailed discussion of these alternative methods see Laker-Ojok 1993a.

2. THE UGANDAN CONTEXT

The importance of the agricultural sector to economic development has long been recognized. Surplus production for sale is the engine of capital accumulation and frees up labor for non-agricultural activities. Agricultural research (broadly defined to include basic, adaptive, and applied research) can lead to the discovery and diffusion of cost saving technology which not only enhances this process but shapes the very direction that development will take. The nature of the technological change determines whether a network of consumption, production, and fiscal linkages between the agricultural and non-agricultural sectors will emerge to contribute to overall development.

As a result of the macro-economic policies and political climate of the 1972-86 period, Uganda underwent a dramatic reversal of the agricultural and structural transformation process achieved in the 1960s. The economic decline during the Amin years was exacerbated by the poor macro-policies and internal unrest of the early 80s. By 1986 Uganda had suffered a nearly total breakdown of agricultural research, seed multiplication, output markets, input distribution networks, and extension services.

Since the inauguration of the Economic Recovery Program in May 1987, many positive steps have been taken to reverse the economic decline of the preceding fifteen years. Farmers have responded to improved security, political stability, and price incentives by utilizing previously underemployed labor and land resources. Donor assistance to rehabilitate infrastructure and to provide credit and inputs have also helped to encourage production increases. The relative freedom from policy-induced distortion in food markets has resulted in market prices which more accurately reflect consumer preferences. Tight fiscal management has finally brought relief from the skyrocketing inflation. Foreign currency markets have been deregulated to allow exchange rates to respond to open-market forces.

The potential for agricultural transformation in Uganda is now much brighter. A major structural reorganization is under way which will greatly strengthen the agricultural sector. This reorganization includes market liberalization in both the input and export markets, rehabilitation of the seed multiplication scheme with particular emphasis on making the scheme self accounting, and the establishment of the National Agricultural Research Organization as an independent parastatal organization capable of offering more competitive incentives to researchers and demanding greater productivity and accountability.

While Uganda's producers have demonstrated a willingness to bring underutilized resources into production in response to price and market incentives, future productivity increases will be much more difficult to achieve. Production increases will have to come from new technology and capital formation. Agricultural research must play a major role in the identification, adaptation and testing of productivity increasing technology appropriate to the farming systems of Uganda. If small farmers in Uganda are to be able to improve their standard of living, generate a larger surplus with which to feed a growing urban population, and contribute to foreign exchange earnings through diversified exports, agricultural productivity must be increased.

2.1. The History of Agricultural Research in Uganda

Uganda has had a long but checkered history in agricultural research. As early as 1908 the Botanical Gardens in Entebbe began the work of collecting relevant germplasm samples and testing potentially valuable non-native tropical crops for possible introduction. The main research stations, Serere, Kawanda, and Namulonge, were founded in 1922, 1937, and 1949 respectively. By independence in 1962, Uganda had a well-integrated system of three major research stations, two agricultural training colleges, a University farm, nine substations, and 46 District Varietal Trial Centers.

Between 1950 and 1972 the majority of the research focussed on coffee and cotton, but a limited amount of work was also done on some 21 other food and cash crops (including sesame and groundnuts). Staple food crops in Uganda vary greatly by region. They include, in order of national importance, cooking bananas (matoke), cassava, sweet potatoes, beans, millet, maize, and sorghum. These crops together accounted for 93% of the land planted in food crops in 1988 (Ministry of Agriculture 1990). The wide range of ecological conditions and food preferences in Uganda puts pressure on research structures to become overextended.

Historically, the commodity of primary research concentration has been cotton. While Ugandan smallholders readily adopted cotton and integrated it into the local farming system, agricultural research, per se, had little impact on cotton yields. The research system was isolated from on-farm realities. Studies show that research impact was con-strained by the lack of consideration for on-farm labor and input constraints (Arnold 1976; Carr 1982; Ferguson 1971). Research impact was further limited by the lack of seed and by organizational problems within the extension service. It was not until 1968 that a seed multiplication scheme was finally initiated. It should be noted, however, that between 1970 and 1988 no new seed varieties were released and seed availability continued to be severely limited.

Ugandan research declined due to the uncertainties and fiscal constraints associated with the Amin regime. Facilities and equipment deteriorated. Staff turnover was high. Vacant research posts were filled, but new staff lacked adequate training and experience. Ugandan researchers were isolated from the world scientific community by the lack of resources for training, travel, and written materials.

The breakup of the East African Community in 1977 further jeopardized Ugandan research. The best facilities in East Africa had been established in Nairobi, Kenya. When the East African Community broke up, Ugandan breeders suddenly had no access to necessary cold storage, computer services, or multiplication facilities. Many of the accession lines being evaluated were kept only in the Kenyan stores and were subsequently lost or damaged. In addition, worsening relations between Uganda and Great Britain led to the suspension of aid to the Uganda Seed Project. Multiplication facilities deteriorated in the face of increasing foreign exchange shortages.

Groundnut seed production declined dramatically from 1975 to 1982. The situation worsened after seed project stores, equipment, and records were looted in 1979. Research activities came to a standstill. Breeder seed could not be provided to the seed project. The Seed Project continued to multiply a limited quantity of certified seed but seed quality deteriorated rapidly as inspection and other quality control activities were suspended. The political instability in the Luwero triangle led to further destruction of the Seed Scheme headquarters at Kawanda Research Station and eventual abandonment of the station in 1985. This seriously delayed implementation of the EEC project to rehabilitate the Uganda Seed Scheme.

2.2. The Research-Strengthening Effort

In 1983 USAID signed an agreement with Uganda to assist with rehabilitation, training, and institutional strengthening under the auspices of the Manpower for Agricultural Development project (MFAD). MFAD concentrated initially on training and the physical rehabilitation of research facilities. Direct investment in commodity research was delayed due to the political instability of the mid-80s. Maize, sunflower, and soybeans were selected as the primary focus of the USAID supported research activities. In 1986, after the massive disruptions of the civil war, research activities on these crops were moved to Namulonge Research Station. In 1987, short-term consultants were brought in to advise the Ministry on the most efficient research strategies for these crops, followed by the appointment of Dr. C. Simkins and Dr. Robert Buker as long-term technical advisors to the maize, soybean, and sunflower programs in 1988 and 1989 respectively. Since 1988 on-station research has been closely linked with on-farm testing. Additional support to these commodities took the form of rhizobium development, seed multiplication and distribution, and the design and dissemination of manual oil pressing technology. The recent ROR analysis for maize, soybeans, and sunflower reports a quite satisfactory return to these investments (table 1).

Minimal local currency funding for groundnut and sesame research was provided by the MFAD project from June 1990 to June 1992. In late 1992 the groundnut and sesame research program began to get funding under the World Bank Funded Headstart for Agricultural Research and Extension project (HARE). This project was initially expected to begin channelling funds to oilseeds research in the 1990/91 financial year, but there were considerable delays in release of funds.

Table 1. The Rate of Return to Maize, Soybean, and Sunflower Research in Uganda[a]

SCENARIO ANALYZED	MAIZE	SOYA	SUN-FLOWER	JOINT
1. Research costs only.	50.6%	9.6%	65.8%	NC
2. Including research, rehabilitation, training, and extension costs at worst case scenario adoption, price, and yield levels.	27.3%	-6.0%	10.3%	16.8%
3. All costs, base case scenario for adoption, yields, and price.	33.2%	4.8%	38.4%	29.8%
4. Ex-ante analysis including all costs, assuming release of higher-yielding variety in 1994.	47.3%	19.9%	51.6%	42.3%

NC = not calculated.
[a] Summary based on data presented in tables 4-7 in Laker-Ojok 1993a.

The mid-term evaluation of the Manpower for Agricultural Development Project - Phase II (USAID 1990) found that small farmer production of soybeans and sunflower was increasing, relevant technology was reaching the farmers, and an increase in food availability and incomes was evident.

During the mid-term evaluation, however, questions were raised concerning the process of research priority setting. The potential importance of the more traditional oilseeds was pointed out. Edible oils, liquid or hydrogenated, comprise a fairly small component of fats consumption in Uganda. Most oilseeds are actually consumed directly, providing calorie-dense high-protein sauces to accompany local staples. The areas planted to groundnut (175,000 ha) and sesame (80,000 ha) far exceed those of soybeans (10,000 ha) and sunflower (2,000 ha) in Uganda (Hartmans 1989). In addition, sesame is increasingly becoming an exportable cash crop alternative to cotton in Northern Uganda. The mid-term evaluation recommended that an assessment of the entire oilseed sector be carried out. It was suggested that the potential payoffs to alternative research investments be evaluated. This analysis is being conducted in response to these recommendations.

2.3. Groundnut Research

Groundnut (*Arachis hypogaea L.*) is the second most widely grown legume in Uganda, the first being the common bean (*Phaseolus vulgaris L.*). The traditional groundnuts are of the red Valencia type, but of a very mixed nature.

The groundnut is high in proteins (25-35%) and fats (44-56%) and provides a major protein source in the Ugandan diet. While groundnuts have been widely cultivated and consumed in Uganda since 1862 (Busolo-Bulafu 1990) there is considerable concern over the apparent instability and decline in per capita production over the past 20 years (Serunkuma, Ekere, and Tumwebaze 1993; Seruyange 1991). According to Ministry of Agriculture statistics, the area planted to groundnuts fell gradually during the early 1970s, followed by a dramatic collapse during the 1979 war that ousted Amin. This resulted in an overall decline of 8.8% per annum for the 1970-80 period. While there has been a gradual recovery of groundnut production throughout the 1980s, groundnut area in 1991 was just over 60% of the peak 1972 official figures. Even more worrying is the decline in national groundnut yields over the years.

In Uganda groundnuts are grown primarily by small farmers. The average national yield of .8 t/ha of dried pods compares unfavorably with the 3 t/ha reported by ICRISAT (1986) to be obtained in countries with developed agriculture. Yields of over 2.5 t/ha have been achieved in experimental plots, however, indicating considerable scope for improved production (Busolo-Bulafu 1990). Researchers identify the following factors as being major constraints to increased production in Uganda: rosette virus disease, early leaf spot (*Cercospora arachidicola* Hori), unreliable rainfall and drought in some areas, lack of high-yielding cultivars, and storage diseases and pests.

Research on groundnuts has been under way since 1930 at Serere Research Station. Before 1960 research concentrated on the collection of local landraces and introduction of cultivars from other countries. In addition some work was done on spacing and row cropping. Most trials were conducted on Valencia type varieties, but some Virginia and Spanish variety trials have also been conducted. In 1963, Anthony Tribe initiated a breeding program aimed at incorporating rosette resistance with some of the desirable characteristics in existing varieties. Desired qualities being plump red kernels, early maturity, adaptability to a wide range of climatic and soil conditions, and disease and pest resistance.

The following varieties were officially released by the Ministry and were multiplied commercially at least briefly: Red Beauty, Roxo, Manipintar, and Makulu Red. Red Beauty (B1), selected at Serere Research Station from among 15 local cultivars, was the variety most extensively produced by the Uganda Seed Scheme. The characteristics of these released varieties are presented in table 2 below.

Three additional varieties, 710 (Brazil), 534 (Venezuela), and Congo Red (Israel) were recommended for release in 1983, but no action was taken. Of the released varieties only Red Beauty and Roxo are being actively maintained by the research program. Furthermore, out of all of these varieties, only Roxo is included in the ongoing variety trials conducted under the World-Bank-funded research program. Maintenance and evaluation of germplasm introductions from ICRISAT is ongoing. In 1992, 58 new germplasm lines were grown for seed increase and preliminary evaluation.

Table 2. The Characteristics of Groundnut Varieties Released in Uganda[a]

VARIETY (SOURCE)	AVE. YIELD KG/HA	TYPE	COLOR	MATURITY PERIOD (DAYS)	OIL CONTENT	ROSETTE SUSCEPTIBILITY
Red Beauty (Uganda)	2,500	Valencia	red	90	51.78%	high
Bukene	2,300	Spanish	tan	110-120	NA[b]	high
Roxo (Venezuela)	2,800	Manyena	red or purple	110-120	47.21%	medium
Manipintar (Zambia)	2,600	Virginia	red & white	NA	45.0%	NA
Makulu Red (Zambia)	2,885	Virginia	red	NA	45.14%	NA

[a] Source: Undated mimeo report entitled, "Groundnut Improvement Programme, Serere." Apparently post-1982.
[b] NA = information not available.

While there is a need for field survey work in order to identify the major production constraints and the magnitude of their impact under farmer condition, it is clear that rosette virus disease is one of the major production problems in Uganda. Rosette virus is transmitted by aphids (*Aphis craccivora*). Heavy infestation can result in complete crop failure. Efforts are being concentrated on the production of resistant varieties since the majority of farmers say they cannot afford chemical control. No systematic economic analysis has been conducted, however. So far, several varieties have been developed by crossing 295, a low-yielding but rosette resistant Virginia type parent line from Senegal, with higher-yielding varieties. These include progeny of earlier Anthony Tribe crosses such as AT4 (295 x Acholi White). AT4 is both rosette resistant and high-yielding (3,100 kg/ha). Unfortunately it is late-maturing (140 days) and dark brown in color as opposed to the red varieties preferred by consumers in Uganda.

A multi-locational variety testing program to compare several of these rosette resistant lines to both the parent stock and Roxo, a local control, has been under way since 1989. The results are presented in table 3.

Table 3. Yields of Breeding Groundnut Lines and Control Varieties 1989-92 [a,b]

Year/Season	1989 1st Rains	1990 1st Rains	1990 2nd Rains	1991 1st Rains	1991 1st Rains	1991 1st Rains	1991 2nd Rains	1991 2nd Rains	1992 1st Rains	1992 1st Rains	1992 1st Rains	1992 2nd Rains	OVER-ALL STD DEV	OVER-ALL MEAN	OVER-ALL CV
Location	A	A	A	A	B	C	A	B	A	B	D	A			
Breeding Line	Yield of dry pods in tons/ha														
X6	1.69	1.68	1.66	1.69	2.02	1.65	0.72	0.51	1.41	1.50	1.61	0.87	0.46	1.42	32.61
X3	1.56	1.56	1.54	1.57	1.75	1.53	0.69	0.59	1.26	1.67	1.43	0.84	0.40	1.33	29.99
AT1 261/5/2/8	1.24	1.24	1.20	1.25	2.19	1.21	0.44	0.48	1.39	1.72	1.28	0.79	0.48	1.20	40.18
AT4 107/2/4/3	1.11	1.59	1.56	1.60	1.82	1.57	0.51	0.55	1.63	1.61	1.48	0.64	0.47	1.31	36.36
AT5 138/2/3/3	1.54	1.53	1.58	1.54	2.43	1.51	0.79	0.44	1.24	1.61	1.53	0.96	0.50	1.39	35.82
AT5 139/6/4/1	1.19	1.88	1.88	1.89	2.07	1.87	0.80	0.47	1.27	1.50	1.57	0.78	0.53	1.43	36.93
AT4 74/3/5/4	1.12	1.34	1.33	1.35	1.82	1.32	0.52	0.40	1.36	1.33	1.35	0.88	0.40	1.18	33.61
AT4 74/3/5/3				1.19	2.08	1.19	0.65	0.71	1.50	1.39	1.51	0.80	0.46	1.22	37.46
RMP-12				1.99	2.88	1.99	1.53	1.57	1.47	1.44	1.31	1.07	0.53	1.70	31.40
Roxo (Control)	1.60	1.59	1.56	1.60	1.98	1.55	0.32	0.49	1.21	1.89	1.29	0.75	0.53	1.32	40.35

A = NAMULONGE, B = MASINDI, C = MUBUKU, D = BUKALASA, STD DEV = Standard deviation, CV = Coefficient of variation.

[a] Sources: Busolo-Bulafu 1990; Namulonge Research Station 1990; Namulonge Research Station 1991; and Busolo-Bulafu 1992.

[b] All trials were planted without fertilizer, insecticides, or fungicides except for seed dressing.

These lines are now in the final stages of evaluation and some are with the Uganda Seed Project for DUS (distinctiveness, uniformity, and stability) testing. The Agricultural Development Project has conducted on-farm trials with RMP12, the most promising of the resistant varieties, since 1990 and Namulonge Research Station intends to conduct further on-farm trials in 1993. It is anticipated that at least one of these varieties will be presented for release by the end of 1993.

In 1976, a program of mutation breeding was also initiated. Induced mutations can often be produced at high frequency, in a short time, and with a selected genetic background. This is easier and less time consuming than the manual emasculation and cross pollination required by traditional methods (Busolo-Bulafu 1990). Trial results since 1989 indicate that two or three of the mutant lines have been able to produce yields significantly higher than Red Beauty and Roxo (Busolo-Bulafu 1990; Busolo-Bulafu and Obong 1992; Busolo-Bulafu and Anyanga 1992). Results are not yet conclusive, however.

Agronomic studies are under way to determine optimal plant density for RMP 12 (a spreading variety) and Red Beauty (a bunch variety) and to identify the cause of purple staining of the seeds of the Roxo variety.

2.4. Sesame Research

Sesame, the oldest oil crop known to man (Nayar and Mehra 1967) has spread into many climatically different regions in the world. It has been speculated to originate in north-eastern Africa (Vavilov 1951; Tribe 1967; Purseglove 1968; Weiss 1971). There are seventeen varieties in Africa out of which *Sesamum indium L., S. angolenese*, and *S. angustifolium* were recorded in Uganda (Greenway 1945; Wanjala 1975). *S. indium*, the cultivated sesame, is the only species of sesamum that has economic importance in the country.

Ninety percent of the sesame produced in Uganda is produced in the northern and eastern parts of the country. These are primarily areas of lower population density with annual rainfall of 1,000 mm (380-500mm during the growing season), temperature ranges of 25^o-35^{o}C, sandy loam soils with good drainage, and higher elevation with lower incidence of leaf disease, webworm, and gallmidges.

Sesame has excited considerable attention in recent years as a potential "non-traditional" export. With falling international prices for coffee and cotton Uganda is being forced to diversify its foreign exchange earning base. In 1990 and 1991 sesame was the third largest foreign exchange earner, following the traditional "cash crops" of coffee and cotton. Foreign exchange earnings from sesame topped $10 million in 1991, more than double the value of maize (Ministry of Finance and Economic Planning 1992).

The research program for sesame (*Sesamum indium L.*) was based at Serere Agricultural Research Station[3] from the 1950s until 1989, when insecurity forced a halt to many research activities. The staff of the sesame program were later relocated at Namulonge and research work was resumed in 1991. The research was multi-disciplinary, including agronomy, pathology, entomology, and breeding work. The objective of the research is to identify technologies which produce stable seed yields, high oil content, and good quality seed for export.

This multi-disciplinary research effort gained significant momentum in 1969 when a world collection of about 2,600 varieties was obtained from Allonge (Tanzania) through Makerere

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[3] Serere Agricultural Research Station, serving the generally drier and less fertile short grass areas north and east of the River Nile, is located about 350 km northeast of Kampala and 30 km southwest of Soroti.

University. This collection contained accessions from Venezuela, U.S.A., India, Tanzania, and South Africa. Varietal screening for disease resistance, non-shattering characteristics, resistance to lodging and uniformity in ripening was begun. Promising varieties were selected for comparison with "S" and Serra the best performing of the known varieties. "S" is a local variety selected by Hirst in the 1950s and released by the Ministry of Agriculture in 1973. Serra (1683) is an ex-USA introduction which was released by the Ministry of Agriculture in 1977 on the basis of its high yields and oil content. "S" was given the status of universal release. Serra received a limited release for the areas of Teso, Lango, and Acholi, the major sesame producing areas, where it reportedly gained considerable popularity. Adoption in other areas of the country is limited by unfavorable weather and topography, high pest incidence, low price compared to other crops, and a preference for groundnuts in the traditional diets of those areas.

By 1973, 47 promising exotic varieties had been identified. Between 1974 and 1977 testing was conducted at the variety trial centers in different ecological zones. The best 12 were compared with Serra and "S," which outyielded all other selections.

In 1978 work began on incorporating shatter resistance and drought resistance into the most promising varieties. Recommended high-yielding varieties were crossed with an indehiscent (non-shattering) but low-yielding variety from Nigeria. One recent report considers this perhaps the most important aspect of the sesame research program. As the report argues, "It is a waste of resources if the other [sesame research] objectives are met, only for the crop to lose the greater part of its yield just before or during harvest, and during field drying" (African Development Bank 1989, Annex C, p. 13). This work came to a standstill, however, even before the in-security problems of the late 1980s, due to the poor conditions of the greenhouse at Serere and the lack of qualified research personnel.

The agronomic recommendations for improvements in sesame production which have been promoted by the Ministry of Agriculture on the basis of past research (row planting, spacing, seed rate, chemical control of pests and diseases, and drying on cement floors) have had little or no impact on farmer's traditional practices (Busolo-Bulafu 1990). Most farmers continue to broadcast sesame. Row planting under farmer conditions is still rare as is any use of insecticides. The reason for the low adoption is that such recommendations fail to consider actual farmer's conditions, the economics of adoption, and the capital constraints of small farmers.

By 1991 efforts to re-establish a germ bank were begun. Five local varieties and 61 international varieties from Ethiopia, Tanzania, Sudan, Somalia, Egypt, Philippines, Sri-Lanka, and India were obtained. Cross breeding work was resumed in 1991. Intercropping trials with millet and maize were also begun that year. Some work is under way to improve the basic understanding of the genetics of inheritance and the correlation between yield and its components for sesame. This contributes to the hybridization program. New work on seed rate recommendations was initiated in the first season of 1992. On-farm trials are supposed to begin in 1993.

2.5. Research Constraints

Groundnut and sesame research have been greatly hampered by political instability and funding constraints. Each of these negatively affected the continuity of the research process and the speed with which research efforts were translated into tangible results that could be extended to farmers. Despite the general rhetoric about multi-locational testing, the number and design of trials has fluctuated greatly over the years and management has been far from satisfactory. Most of the Variety Trial Centers are in very poor condition, and even where they are functional, lack of funding limits the number of possible trial locations.

Much of the groundnut and sesame germplasm was lost or destroyed during the political insecurity in Northern Uganda between 1987 and 1989. All available genetic stocks were maintained at Serere, which had no cold storage facilities, necessitating regular planting to regenerate seed stocks. Not only was such regeneration impossible during the period of political chaos, but seed stocks were broken into causing considerable loss from physical mixing. Elite sesame materials which were salvaged from Serere required considerable reselection effort in order to restore purity of the strains. In 1976 the assembled germplasm collection for groundnuts had reached 900 cultivars; by 1990, this had fallen to 350.

The loss of research results is even more serious. Lost germplasm may be replaceable from external sources. The loss of field results, however, may require years of effort to duplicate previous work. The few available reports make frustrating reference to extensive investigation of the entomology of sesame pests, pesticide screening, seed rate, and intercropping, the results of which are no longer available. The fate of the new varieties developed by the breeding programs is also unclear.

Even in the absence of insecurity, inconsistency in the flow of funds continues to result in a great deal of wasted effort. During the first season of 1992 groundnut trials were planted at 9 locations (Namulonge, Bukalasa, Ngetta, Ikulwe, Masindi, Mbuku, Nakabango, Tororo DFI, and Iki Iki). By the end of the year, however, results were available from only three of these locations. The other trial results were never retrieved due to lack of funds. Data that were supposedly collected on disease scores, days to maturity, dry pod weights, shelling rate, and seed weight have never been analyzed even for those locations where results were collected.[4] Second season trials had to be limited to only two locations because funds were not available to dispatch seed and prepare fields. Groundnut agronomy trials on planting date, inter-cropping, weed control, fertilizer and pesticides have apparently been abandoned, once again due to lack of funds. It is virtually impossible to develop and verify appropriate technical packages for extension to farmers with such an inconsistent research effort.

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[4] Chances are that these data will never be retrieved or analyzed. Nearly every report indicates that this information has been collected, but not a single analysis of the data can be found.

3. ANALYSIS

3.1. Analytical Procedures

The steps in the basic benefit-cost analysis are as follows:

(1) Calculation of gross benefits, both "without-research" and "with-research."

  (a) Determination of the area and yield levels for both traditional and improved technologies for the life of the project. When benefits are being projected into the future, the estimation of area for the improved technology requires prediction of the expected adoption level for each year of the analysis.

  (b) Determination of the price at which production should be valued. The purpose of an economic analysis is to measure the total net benefits to the economy as a whole rather than to the individual producer. The price, therefore, should be adjusted for exchange rate distortions, subsidies, and taxes, which are simply a transfer between sectors within the economy, in order to reflect the real economic value of increased production.

(2) Calculation of incremental gross benefits. Production benefits which would have been achieved in the absence of the research are netted out because they would have been achieved even without the research.

(3) Calculation of incremental ("with-research" minus "without-research") production costs per year attributable to adoption of the technology.

(4) Determination of annual research costs. One major difficulty encountered in evaluating the rate of return to agricultural research is the problem of separating the impact of research from that of complementary investments in extension, institution building, training, promotion, and diffusion. In the absence of sufficient data on these investments, however, it is necessary to include all of the relevant investments as costs and report the returns to research and extension jointly.

(5) Calculation of the annual incremental net benefit. This is the incremental gross benefit minus the total costs (incremental production costs plus the cost of research, rehabilitation, training, diffusion, and extension).

(6) The stream of annual incremental net benefits then needs to be deflated by an appropriate cost of living index to reflect its real value in constant prices. This is especially important in a highly inflationary economy such as that of Uganda in the mid- to late 1980s.

(7) Calculation of the rate of return. The Internal Rate of Return is the discount rate that equates the present value of the net benefit stream to zero. This rate can then be compared

to the interest rate or some other estimate of the cost of capital to determine the profitability of the investment.

(8) Lastly, sensitivity analysis is conducted to test the stability of the ROR and the relative importance of its various components (price, yields, adoption). This is one means to specifically incorporate the possible effect of market imperfections and changes in macroeconomic policy variables into the analysis.

Because no new varieties have yet been released, the calculation of the ROR to groundnuts and sesame research in Uganda is essentially an ex-ante analysis. It incorporates the known cost of research in recent years together with projected costs under the HARE project. The benefits, however, are entirely in the future. This necessitates predictions concerning farmers' adoption response, market conditions, and institutional support for technology transfer. The uncertainty of the resulting rate of return, highlights the importance of sensitivity analysis. The ROR estimates calculated in this analysis are an approximation at best. Their usefulness lies primarily in the issues they raise regarding the factors necessary to achieve a reasonable payoff to research investment.

3.2. Data Sources

Information for this analysis was obtained through extensive informal interaction with researchers, extension agents, traders, policy makers, processors, and producers. Limited time and resources precluded large-scale formal survey confirmation of parameters. Informal reconnaissance surveys and in-depth interviews with key informants at different levels of the subsector were used to supplement the available secondary data.

The data sources for the key parameters in the analysis of both commodities are similar and will be discussed jointly to avoid repetition. These parameters are yield, area, adoption/ diffusion projections, price, production costs, and research costs.

Given the high degree of uncertainty involved in the projection of benefits, a decision was made to underestimate the benefits and overestimate the costs. While researchers may feel that I do them an injustice by understating their accomplishments, I feel that this approach gives greater credibility to the results. Given the conservative nature of the analysis, the highly acceptable returns to both groundnut and sesame research are encouraging.

It should also be pointed out that estimated areas, yields, prices, extension costs, and maintenance breeding expenditures are held constant for the projected life of the analysis. This is obviously an unrealistic assumption since all of these values are sure to vary over time. However, there is no evidence on which to base a more accurate projection of future changes. Clearly external factors outside of the central issue of this analysis will affect the future level of these parameters and will in turn alter the realized ROR to the research investment. The results of the analysis, therefore, are indicative at best and should be interpreted accordingly.

3.2.1. Yield

While multi-locational trial data are available for both crops, the question of what yield to use for this analysis is subject to debate. Yield is a highly complex phenomenon, resulting from the interaction of farm management decisions regarding crop rotations, intercropping, planting date, weeding, insecticide and fertilizer use; environmental conditions such as soil fertility, rainfall, and temperature; as well as the genetic qualities of the variety. In addition, destruction by domestic animals and cash flow crises which result in failure to harvest research plots may also affect yields. Often such factors are poorly documented.

Researchers rely primarily on results from on-station research when evaluating variety performance precisely because on-station the researcher is able to control many of these sources of variability. The problem is that on-station conditions rarely mirror the farmer's production constraints. Research stations are generally located on higher-productivity land and have been managed quite differently than the average farmer's field. Care is taken to provide good management practices at the research station including clean weeding, timely planting, pest control and fertilizer application. Such practices are rarely followed by farmers, who are constrained by the demands of manual cultivation, input shortages, and limited labor supply.

For these reasons, yield advantages demonstrated on-station, while indicative of the potential of the variety, are not a good predictor of expected yields under farmer conditions. Nor can one simply resort to national production statistics in Uganda to obtain a reasonable estimate of yields. National production figures are based on very rough estimates by extension agents concerning the area under their jurisdiction which has been planted to a particular crop. These rough area figures are simply multiplied by a standard national yield estimate adjusted somewhat to account for current local conditions such as drought, disease outbreak, or political insecurity. The recent national agricultural census, the first to be undertaken since 1963, may be able to provide a more accurate picture in the future, but the data are not yet available.

No on-farm trials have been conducted for sesame, and ADP's on-farm testing program for groundnuts has been very limited. VTC trial results have always been highly variable due to poor management with total failure not uncommon. Problems include delayed planting, poor weeding, and lack of disease control. In contrast, when better management was maintained at Serere, groundnut yields reach nearly 2,750 kg/ha for most varieties.

Data limitations make it difficult to judge the significance of the yield results from the multi-locational groundnut trials. Despite Uganda's long history of agricultural research, it is very difficult to pull together information at the necessary level of detail to be able to make comparisons across years and locations. For example, multiple years of replicated trials are required before the extent and significance of rosette resistance can be accurately assessed. The new resistant varieties need to be compared to both chemically protected and unprotected non-resistant strains under varying levels of disease pressure in order to assess the significance of resistance and its economic costs and benefits. This information then needs to be combined with additional information concerning the extent of the rosette pressure in different parts of the country to assess the expected yield impact in each region.

Yield estimation for groundnuts is further complicated by the fact that they store best in the shell. Farmers harvest and dry the groundnuts and then store them either in gunny bags or loose in a mud and wattle granary. Farmers generally sell their groundnuts still in the shell. Nuts for home consumption are shelled as the need arises. As a result, the farmer's primary impression of yields is in terms of production in the shell.

Research yields are also generally reported in terms of kg of dried pods/ha. This measure, however, ignores the important factor of shelling percentage as a determinant of the final quantity of shelled nuts. The significance of this factor is illustrated with data from a recent report (Miller 1991). On-farm trials in Kitgum District found that the shelling percentage[5] varied from 57.7% to 70.8% depending on the number of seeds per pod and the proportion of unfilled pods. As a result, yield rankings change depending on whether they are based on the number of bags, the total dried pod weight or the seed yield.

This finding is illustrated in table 4. Three local varieties were compared with two released varieties, Red Beauty and Roxo, and two experimental rosette resistant crosses, RRS I and RRS G.[6] As the rankings show, Red Beauty clearly out-yields the rest while Angamatonga and Kalanga yield the least. Roxo's performance, however, depends on which measure of yield is used. It ranked second in terms of number of bags but fifth in terms of either of the weight measures. This indicates a much higher ratio of bulk to weight than the other varieties.[7] Conversely, RRS G had a higher than average ratio of seed to bulk. Measurement by the bag underestimates the yield of seed from the improved variety.

The farmer who sells groundnuts by the bag will not see the advantage of growing a variety with a higher yield of shelled seed unless better grades are reflected in the sales price. No formal grading system exists in the Ugandan rural markets. A strong bargainer can get a

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[5] Shelling percentage is the ratio of the weight of the seeds alone to the total weight of the pods prior to shelling [100 x (weight of seeds)/(weight of seeds + pods)].

[6] RRS I and RRS G probably refer to the same varieties as AT5 138/2/3/3 and AT4 74/3/5/3 in table 3.

[7] The average bag of Roxo weighed only 42 kg as opposed to over 50 kg/bag for the two experimental varieties.

Table 4. Alternative Groundnut Yield Rankings in Kitgum District Depending on Yield Measure Used[a]

Variety	Shelling %[b]	Dried Pods kg/ha	Rank	Seeds kg/ha	Rank	Bags per ha	Rank
Angamatonga	70.8	955	7	676	7	19.8	7
Kalanga	68.3	1,189	6	812	6	27.9	6
Roxo	65.2	1,321	5	861	5	31.2	2
RRS I	57.7	1,565	2	903	4	29.8	4
Lajeba	68.9	1,462	4	1,007	3	29.9	3
RRS G	70.6	1,466	3	1,035	2	28.9	5
Red Beauty	70.8	1,716	1	1,215	1	39.9	1
LSD (p=.05)[c]	2.1	NA		200		6.8	

somewhat higher price for higher quality in face to face transactions, but this is not possible for bulk purchases or long distance sales.

The decision was made to use the national average yield for the past 20 years as reported by the Ministry of Agriculture as the without-research yields. Yield increments of 60% for groundnuts and 50% for sesame were attributed to research in the base case. This contrasts with the 100% yield increases being predicted by researchers on the basis of their on-station trials.

3.2.2. *Area*

Total area figures for the without-research scenario for groundnuts and sesame during 1986-91 are based on national estimates prepared by the Ministry of Agriculture, Animal Industries and Forestry. No expansion in area is attributed to the research effort. In the absence of any evidence which would allow reliable projections about expected trends, area planted to groundnuts and sesame is held constant at 1991 levels in the future projections.

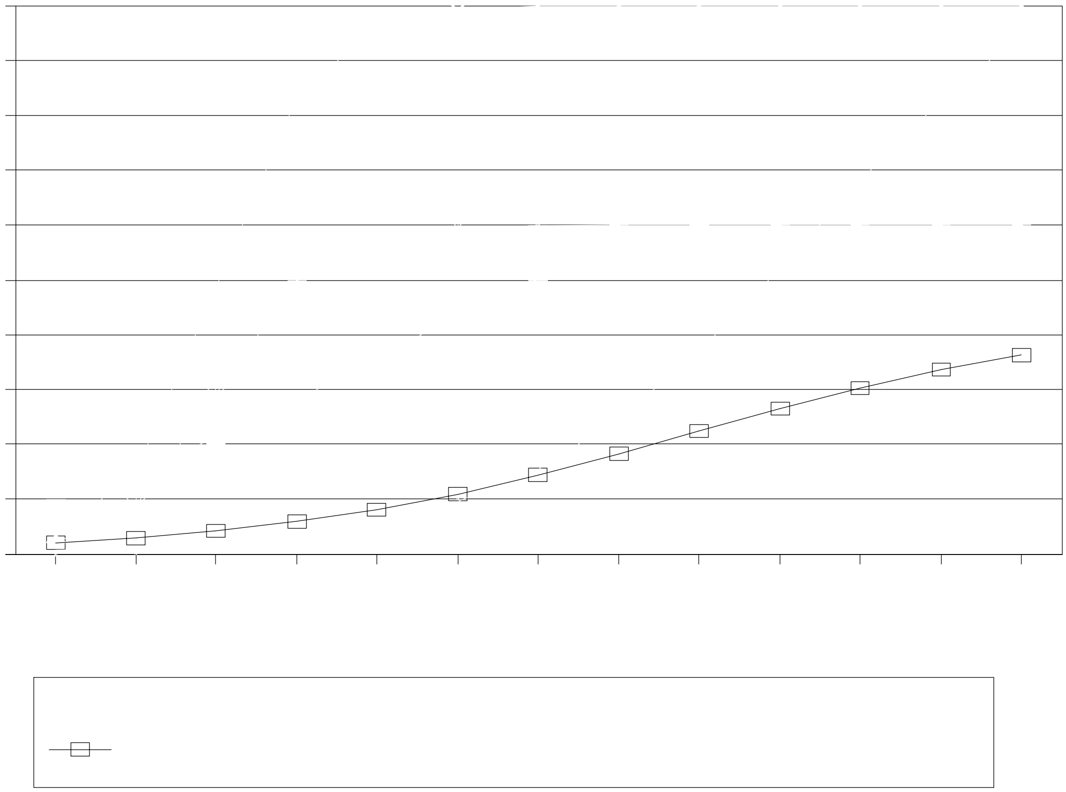
Since the new varieties have not yet been released they have no adoption history that can be used as a basis for projected adoption rates. Groundnuts, however, were very important in the seed multiplication efforts of the 1970s. The available data on seed sales and likely seed retention rates by farmers are therefore used as a reasonable guide to likely future adoption of the new varieties. A standard log function with the usual S-shaped adoption curve over time was fitted to the 1970-79 adoption figures for groundnuts using Ordinary Least Squares regression analysis in order to determine the value of the equation parameters (y intercept, as well as a and b which determine the nature of the curvature) given alternative estimates of the adoption ceiling. The curve with the best fit, or highest explanatory power (as reflected in the R^2) was then selected. This procedure is an algorithm. These parameters were then used to project the anticipated adoption levels for the period after release of the new variety. Sensitivity analysis was then used to assess the impact of cutting the projected adoption ceiling.

For sesame there is no historical precedent on which we can base our projections for variety adoption. While two sesame varieties have been released in Uganda, they have never been multiplied by the Seed Scheme and therefore were not available to farmers on a commercial basis.[8] There are reports that Serra became quite popular and was dispersed through informal farmer-to-farmer transmission, but no corroborating data exist.

In the absence of any data on which to base sesame adoption projections, it was decided to use sensitivity analysis to see how important adoption rate is to the final ROR figures. The ROR analysis was conducted using five different adoption rates, i.e. the projected rates for maize, sunflower, soybeans, and groundnuts as well as the estimated adoption ceiling proposed by the panel of experts during the NARO agricultural research priority setting exercise (Republic of Uganda 1991). Figure 1 illustrates the difference between these alternative adoption paths. They vary not only in the ultimate adoption ceiling, but also in the speed of adoption as indicated by the slope of the curve. Further details concerning the estimation of the adoption equations for groundnuts and sesame can be found in appendix 1.

[8] Sesame seed sales by the Uganda Seed Scheme in 1990 and 1991 were actually commercial seed, not certified seed. This means they bought sesame from local farmers, cleaned it and tested it for germination rates. This sesame is sold as seed, but it is not of any particular known variety.

Figure 1. Relative Adoption Rates by Commodity



3.2.3. *Price*

The appropriate price at which to value the increased production from improved technology depends upon a number of factors. These include (1) whether production is to be sold on the domestic or the export market, (2) the structure of that market, and (3) the relative impact an increase in supply is expected to have on the price. The Ugandan market for food commodities has historically been largely free of any distortion. The expected increase in total production of both groundnuts and sesame due to research is relatively small. Given anticipated population increases, the increased production is unlikely to have any real impact on the relationship between supply and demand.

The primary market for Ugandan groundnuts is expected to continue to be that for direct domestic consumption. Groundnuts are unlikely to be imported or exported in any significant quantities. During the 1960s groundnut exports peaked at 7,000 tons per year. Approximately an additional 5,000 tons of groundnuts were purchased by millers for crushing. Only a small proportion of the resulting oil and cake was exported. Crushing of groundnuts remained on a very small scale, however, because it was more profitable to shell the groundnuts and resell on the domestic urban retail market (Coles 1968). During the 1970s official exports dried up entirely due to marketing controls but undocumented quantities continued to be smuggled across the border. Even this smuggling dried up with the falling international prices of the 1980s. While 239 tons of groundnuts were exported by Foods and Beverages in 1991, these barter trade deals have been negotiated primarily for political reasons and have not been very lucrative.

A recent study by the Agricultural Secretariat reported a Domestic Resource Cost Ratio for groundnuts of 1.04, indicating Uganda's relative lack of comparative advantage in groundnut exports (Agricultural Policy Committee 1991, p.10). A DRC ratio over 1.0 indicates that the domestic resources required to produce the commodity are worth more than the net foreign exchange that could be generated by the export of that commodity at current world market prices. Low yields under Ugandan conditions, and low international prices compared to the high cost of transportation, contribute to this finding. For these reasons, the 1991 domestic price for groundnuts, as reported by the Ministry of Commerce, Cooperatives and Marketing is used.

The situation for sesame is in sharp contrast to that of groundnuts. The Agricultural Secretariat reported an extremely low DRC ratio for sesame (0.58) indicating a strong comparative advantage.[9] The domestic demand for sesame, while stable, is not that substantial outside of the northern part of the country, whereas the export market has been excellent in recent years. For this reason, all sesame scenarios value additional production at its international price (FOB Mombasa), adjusted for the foreign exchange costs of marketing from the farm gate to final

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[9] op. cit., p. 10 and Annexure 7 (b).

destination.[10] Export taxes are not deducted because those constitute transfer payments within the Ugandan economy. Alternative scenarios, however are included to provide information concerning the impact of alternative trends in the international market. The base case uses the average per kg value (foreign exchange earnings) from sesame exports in 1991 as the CIF Mombasa price. This price is substantially lower than the Agricultural Secretariat's estimate of the CIF price of sesame, however. Sensitivity analysis was used to test the impact of raising the price to the $700 per ton (Agricultural Secretariat 1990). Another scenario was also run using $900 per ton under the assumption that with a pure variety Ugandan sesame will be able to penetrate the higher-priced Japanese market.

3.2.4. Production Costs

The objective of the benefit-cost approach is to quantify the net benefits accruing from the investment in agricultural research and extension. This means that the value of the production which would have existed even in the absence of research is subtracted. Similarly, only the costs which exceed those which are necessary in the absence of the new technology are netted out. Because the technologies being evaluated here are very simple, there are few additional production costs to be considered. The assumption that the majority of farmers in Uganda do not use fertilizer has already been reflected in the choice of yield level for our analysis. For this reason, no additional cost of fertilizer or chemicals is assumed. The only additional labor required by the new varieties would be the extra harvesting and post-harvesting efforts necessitated by the higher yield.[11]

Because the new varieties are open-pollinated, farmers will be able to plant their retained seed for a number of years after initial adoption of the new variety. They will, however, have to purchase the initial seed, whether from the Seed Scheme or from another adopting farmer. The cost of initial seed purchase for first-time adopters of the improved groundnut and sesame varieties, then, is an additional cost of adoption. Groundnut and sesame seed are valued at the Uganda Seed Scheme sales price for 1992.

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[10] The cost of marketing sesame from the farm gate to Mombasa are estimated to equal about $112 per ton. This is reasonable given the high value of the crop. The Ministry of Planning reports that the 1991 sesame exports earned an average of $590 a ton. The calculation of marketing costs is based on information provided in Bro 1992.

[11] Technically, the way to solve this problem is to use a field price for the commodity, i.e. the farm gate price less the cost of harvesting, transportation from the field, and post-harvest processing. The scarcity of data made it impossible to calculate such a per kg field price. The additional costs are expected to be minimal, however, and are unlikely to affect the analysis to any substantial degree.

3.2.5. Rehabilitation, Research, Promotion, and Extension Costs

This analysis is based on both past and projected costs of research. In economic analysis all costs and benefits are viewed from the perspective of the society as a whole rather than that of a single organization or individual. For this reason, expenditures such as taxes which might be a cost to the individual are excluded because they represent a transfer from that individual to the government. They are not a cost to the society as a whole. In a similar manner, subsidies are also an internal transfer.

The most significant issue in the Uganda case is the issue of overvalued exchange rate. In the early to mid-1980s Ugandan macroeconomic policy was based on a grossly overvalued exchange rate. This left the demand and supply of foreign exchange in perpetual imbalance and required extensive rationing mechanisms to enforce. The extent of imbalance is often expressed by a ratio called the percentage gap. This ratio expresses the percent of the official rate by which the open-market rate exceeds the official. During the time period under consideration the percentage gap first rose from its 1985 level of 149.2% to a 1987 peak of 409% before slowly falling to a low of 28% in 1991. When US$ investments in research and rehabilitation are converted to Uganda shillings (USh) at the official exchange rate they grossly under-represent the real value of the resources that have been spent. For this reason, all hard currency investment is valued at a shadow exchange rate which reflects their scarcity value. An estimate of the open-market exchange rates was obtained from the Bank of Uganda for the period of our analysis. This shadow exchange rate was used to value all hard currency costs. While it may be argued that a black market rate overstates the level of distortion due to risk, this is the best information available. In addition, it is consistent with the decision to use "conservative" estimates throughout the analysis.[12]

In August 1990, the open-market exchange system was legalized by the creation of foreign exchange bureaux. The bureau rate is used to value all post-1990 hard currency investments.

Another difficulty is that project accounting systems are not designed to document expenditure according to the category of expected impact. It is difficult to identify which investments contribute to research impact as opposed to general manpower development in the agricultural sector. The researcher must make a judgment call concerning which expenditures to include.

The ROR analysis has been conducted on three levels, demonstrating the impact of expanding the definition of "research costs." The first level included only those costs directly associated

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[12] The level of risk premium is probably very small, given the openness with which the black market functioned during this time period. At various times during this period there was an official two-tiered exchange system (window one and window two). Even when the two-tiered system was not functioning, the open market rate was well known. Referred to as the "door rate," it was published on the front page of many newspapers each week. No serious attempts were actually made to enforce the official rate or penalize those who traded on the black market. In fact, black market exchanges were actually made right on the premises of most major banking institutions.

with the research, i.e. the government of Uganda investments in the two commodity programs, local currency USAID and World Bank contributions to on-station research costs, and hard currency investments in equipment under the World Bank funding. Future costs were estimated using approved program budget projections and assuming a minimal level of maintenance breeding expenditure in the period following projected release of the new varieties.

The second level added the cost of training scientists connected to the commodity programs, and the rehabilitation of the research facilities and equipment. A rather arbitrary decision was made to allocate one sixth of the rehabilitation costs for Namulonge research station[13] to these two commodities and to divide this investment equally between them.[14] A related proportion of the management and indirect costs of the implementing institution was included.

The addition of training and rehabilitation investments meant a considerable front loading of costs compared to the direct research investments. Physical rehabilitation began as early as 1985 and training was in full swing by 1987, whereas direct research supplements did not begin until 1990.

There are many benefits from the training and rehabilitation investments which are difficult to capture in an ROR analysis. Just because the scientist who is trained is a groundnut breeder is no guarantee that he or she will always work on that commodity. The improvement in the human capital base, however, is expected to lead to benefits somewhere within the agricultural sector. Similarly, investments in housing and research facilities may serve other commodity programs as well as enhancing such intangibles as scientist morale and sense of commitment. If these were investments in durable items such as equipment, the ROR analysis would incorporate a salvage value for the item into the benefit stream at the end of the project. However, such a salvage value is difficult to estimate for improvements in human or institutional capital, especially in Uganda where the salary of a scientist is such a poor reflection of the value of his/her contribution.

Rehabilitation and training are necessary investments. They are essential to research success and must somehow be incorporated into the analysis. For this reason, the inclusion of the share of rehabilitation investments which can reasonably be attributed to the groundnut and sesame programs is valid even though not all of the benefits accruing to these investments can be captured in the analysis.

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[13] Identifying the costs of physical rehabilitation, equipment and supplies for Namulonge research station was itself a difficult exercise given that expenditures for Namulonge were not separated in the accounts from those for Serere Research Station, the Faculty of Agriculture and Forestry building on campus, the university farm, and minor work on various other substations. This raises the important issue of designing financial accounting/reporting procedures with impact assessment in mind.

[14] This seemed a reasonable if conservative decision given that Namulonge Research Station is also the home of other important commodity programs such as cotton, maize, sunflower, soybeans, cassava, rice, cowpeas, and animal traction.

The third level of costing includes extension services. Once the new varieties are released and become part of the seed multiplication and diffusion system, the extension service will have to play an important promotional role. To a large extent the costs and impact of such promotion are unknown. The Ugandan extension system is in a general state of disarray. Extension agent morale and commitment is exceptionally low as a result of the abysmal terms of service. Effectiveness is limited by the lack of such basics as transportation and demonstration materials.

Detailed information about the level of investment in extension services is difficult to obtain. The World Bank reports that in 1990 the Government of Uganda employed 3,185 agricultural extension agents at an annual cost of just $350 per agent including supervision, materials, and Ministry overheads. This analysis assumed that extension agents dedicate effort to commodity promotion in proportion to the relative importance of that commodity in the farming system.[15] Based on this assumption, the annual extension cost was apportioned according to the percent of cultivated land area devoted to groundnuts and sesame. In the absence of future projections, extension costs were held constant at this level for the duration of the analysis.

The expected impact of such extension activity is difficult to predict. The existing extension system is undergoing a fundamental re-organization in order to reduce staff numbers and enhance efficiency and productivity. The transmission of clearly formulated, relevant extension messages is emphasized. Diffusion of improved varieties is one easily identifiable target. Future monitoring and evaluation of the extension system pilot project may provide a better means of measuring extension impact. In this analysis, however, no particular increase in benefits is attributed to the inclusion of the extension effort.

3.2.6. Inflation

The last step in calculating the benefits from research is to transform the nominal value of the net benefit stream into a real value. This controls for the effect of inflation. Ugandan inflation exceeded 200% in 1987. In addition, there was a major currency reform in Uganda in 1988. The net benefit stream is standardized by converting all nominal values to constant 1989 prices using the New Kampala Consumer Price Index.[16] While a Kampala based price index is not the ideal measure, no rural price index is available. All post-1992 prices are held constant and therefore continue to be deflated by the estimated 1992 CPI.

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[15] While reasonable on the surface, the validity of this assumption is difficult to gauge. Out of 281 farm households, 18.6% report having been advised about groundnut production by an extension agent. The proportion for sesame was only 4.4%. The relatively low level of extension advice for sesame is undoubtedly related to the fact that only one of the five survey areas is a major sesame producer. Furthermore, researchers have yet to formulate any significant production recommendations or technologies that can be extended to sesame farmers.

[16] The New Consumer Price Index (September 1989 = 100) was spliced with the old Kampala Cost of Living Index, Low-Income Group, using calendar year 1988 as the overlap period. The consumption basket used for the two indices differ, but the level of accuracy achieved in this manner should be adequate for our purposes.

3.3. Results of the ROR Analysis

3.3.1. *Groundnuts*

The results of the ex-ante ROR analysis for groundnuts is reported in table 5. Rates of return are reported for three timeframes for each alternative scenario, i.e. through 2006, 2001, or 1996. This mode of analysis demonstrates the difference in results which will likely arise if adoption and benefits are prematurely cut off due to economic or political factors. Red

Table 5. The Rate of Return to Groundnut Research in Uganda

SCENARIO ANALYZED	1985-2006	1985-2001	1985-1996
1. Research costs only.	44.4%	41.0%	24.1%
2. Research, rehabilitation, and training costs.	37.7%	33.4%	14.3%
3. Research, rehabilitation, training, and extension costs.	37.1%	32.6%	12.1%
4. All costs, yield increased to 1,500 kg/ha.	43.1%	39.5%	22.0%
5. All costs, adoption ceiling cut to 11%.	29.2%	23.2%	-3.4%
6. All costs, adoption ceiling cut and yield cut to 1,000 kg/ha.	23.1%	15.5%	-21.7%
7. All costs, price raised to 1992 drought average and yield raised to 1,500.	46.3%	43.1%	26.9%
8. All costs, release delayed until 1996.	30.1%	22.3%	-21.5%

Beauty, the improved groundnut variety which has dominated the seed multiplication effort, was released more than twenty years ago. Given this history, a projection of benefits from research for ten to fifteen years into the future does not seem at all unreasonable.

Scenarios 1 to 3 illustrate the impact on the ROR of incorporating increasing levels of the supporting institutional costs into our analysis. The first scenario, which includes only the direct costs of research, shows an ROR of 24.1% after the year 1996. This means that if we exclude the cost of extension, research station rehabilitation, training, and their associated indirect costs, the benefits from increased groundnut production more than equal the value of the direct research investment only two years after the release of the variety, achieving a 24% rate of return on investment. Surprisingly, the rates of return continue to be positive after 1996 even when rehabilitation, training, and extension costs are included (scenarios 2 and 3).

The ROR estimates for 2001 and 2006 look very good, no matter which scenario is being considered. To evaluate these returns it is necessary to have an estimate of the opportunity cost of investing in research as opposed to other possible alternatives. What are the normal returns to investment in the Ugandan economy today? This is difficult to say. Profit margins are often obscured by rapid national inflation and by hidden or uncounted costs of operation. The interest rate for borrowed investment capital in Uganda is currently running at over 40% per annum, but with inflation at 30% or higher, this leaves a real interest rate in the range of 10%. The interest to be earned from holding funds in a savings deposit, however, is still highly negative. Given the current tightness in the Ugandan economy, an opportunity cost of capital in the range of 10%-15% seems like a reasonable estimate for comparison. An ROR of 12% to 44% from investment in groundnut research, then, is more than acceptable. For the purposes of the sensitivity analysis, scenario 3 was taken as the base case for comparison.

In scenario 4 the yield of the improved variety was increased to 1,500 kg/ha. This is the average yield obtained for the RMP12 rosette resistant variety in on-farm trials in Lira District. Scenario 5 demonstrates the impact of cutting the projected level of adoption in half. Scenario 6 compounds this cut in adoption by reducing the projected yield for the improved variety to only 1,000 kg/ha, which is substantially less than the results obtained in on-farm trials. Scenario 7 illustrates the impact of having both high yield and a higher domestic price. This scenario used the average 1992 price for groundnuts. This price was not used in the base case because it was felt that the poor harvest resulting from the 1992 drought had raised prices to an artificial level. Last of all, scenario 8 illustrates the impact of delaying the release of the new variety by an additional two years.

All of the ROR figures obtained in the alternative scenarios are very acceptable, suggesting a very high potential payoff to groundnut research investment.

3.3.2. Sesame

The results of the ex-ante ROR analysis for sesame is reported in table 6, using a similar format to that employed for groundnuts. Once again scenarios 1 to 3 illustrate the impact of including increasing levels of costs into the analysis. Overall, the returns to sesame research exceed those for groundnuts.

The lack of information concerning the likelihood of adoption of a new sesame variety, however, makes these results less certain. Scenarios 4 through 7 test for the impact of altering the adoption pattern. It is obvious that the results are quite sensitive to alternative adoption assumptions. The faster the pace of adoption, the higher the returns to the research. This highlights the vital importance of an adequate seed multiplication and distribution system.

Scenarios 8 and 9 illustrate the impact of either lowering the yield increment expected from the new variety or delaying its release until 1996. In the event of a delayed release, the ROR falls to a barely acceptable level by the year 2006. This demonstrates the importance of consistent research funding to avoid unnecessary setbacks and delays.

Table 6. The Rate of Return to Sesame Research in Uganda

SCENARIO ANALYZED	1985-2006	1985-2001	1985-1996
1. Research costs only, assuming adoption level similar to soybeans.	49.0%	46.9%	30.5%
2. Research, rehabilitation, and training costs, assuming adoption like soybeans.	42.9%	40.3%	22.1%
3. Research, rehabilitation, training, and extension costs. Base case scenario.	42.5%	39.8%	21.1%
4. All costs, assuming adoption pattern like groundnuts.	27.3%	20.3%	-12.3%
5. All costs, assuming adoption pattern like maize.	28.9%	16.0%	-49.7%
6. All costs, assuming adoption pattern like sunflower.	43.6%	41.5%	5.3%
7. All costs, assuming 50% adoption ceiling as proposed by researchers.	49.8%	48.0%	14.5%
8. All costs. Base adoption. Assumes yield increment only 25%.	20.2%	11.1%	-35.6%
9. All costs. Base adoption. Assumes variety release delayed until 1996.	15.3%	1.9%	-25.2%
10. All costs. Base adoption. Assumes Japanese level export price for pure variety only.	56.7%	55.0%	39.5%

Lastly, scenario 11 illustrates the important benefits that can be captured if release and multiplication of a pure white strain of sesame allows Uganda to break into the larger, more lucrative market in the Far East.[17]

3.3.3. Uncaptured Benefits

Many of the positive impacts of agricultural research are not easily captured by an ROR analysis which focusses primarily on benefits from increased production. This is certainly true in Uganda. Agricultural research on groundnuts and sesame has important gender implications for the Ugandan farming system and the distribution of income within the household. Both commodities are less firmly situated within the male sphere of influence than are the more traditional cash crops such as coffee, cotton, tea, and tobacco. Women participate fully in the production and marketing of groundnuts and sesame.

Another benefit which is difficult to quantify is the extent to which research investments have strengthened the human capital base and institutional capacity of the country. Institutional and human capital development are investments which have positive payoffs far into the future and across a broad spectrum of commodities and research efforts. The increase in knowledge and skills not only enables the replacement of external research advisors with nationals, but results in an increased earning capacity for the scientists involved.[18] To the extent that investments in technical advice, training, and rehabilitation are included in the costing of the research investment, they result in a very conservative estimate of the returns to research. The history of research in Uganda illustrates the impossibility of turning research off and on. It takes only a short lapse in research support to result in massive losses in human and physical capital which will require painful and expensive new investments to overturn.

Lastly, the prioritization of research efforts between different commodities has serious regional equity implications. This is especially true for sesame. Farmers in Northern Uganda have shown keen interest in expanding sesame production in order to diversify their sources of income. Given the historical concentration of economic activities and development in the south, efforts to increase incomes in the northern region are of particular interest. The importance that the Ugandan government places on economic development for this region is demonstrated by the recent efforts to initiate a major reconstruction project for the North, financed by the World

[17] At present, most Ugandan sesame is being exported to the Middle East, where quality standards are less rigorous, but prices are accordingly lower.

[18] One possible way to try to quantify the benefits accrued from the training would be to estimate this enhanced income stream. Unfortunately, given the current low salary structures in the public service, the use of official salary scales would grossly underestimate the value of this training which is more likely to accrue in more informal forms (such as consultancy fees, travel opportunities, and other perks involved in working for donor funded projects, promotion outside of the public sector and private business earnings).

Bank. The perception of visible government concern for the development of the North could even have implications for future political stability in Uganda.

4. IMPLICATIONS FOR THE RESEARCH PRIORITY-SETTING PROCESS IN UGANDA

In recent years many experts have been urging national agricultural research systems in developing countries to adopt more formal priority-setting methods in order to help them improve the relevance and pay-off of research (Norton and Pardey 1987, Bottomley and Contant 1988, Raman 1989, Javier 1989, Dagg 1991, Collion and Kissi 1991). A variety of tools to assist in this process have been designed. These range in complexity from simple checklists and tests of congruence to complex mathematical programming models.[19] Each has its own comparative advantage. The selection of what tool or combination of tools to use should depend on the adequacy of the data; the finances, manpower, and time available; and the economic importance of the decision. The two most widely used methods are weighted criteria scoring methods and benefit-cost analysis.

4.1. Comparison of ROR Results with Rankings from the Weighted Scoring Method

Uganda is in the process of a major reorganization of the entire agricultural research system. A semi-autonomous National Agricultural Research Organization is being created which will be responsible for agricultural research planning, management, and evaluation. As part of this structural re-organization process an extensive priority-setting exercise was conducted in 1990 using the Weighted Scoring Approach (Republic of Uganda 1991).

In the weighted scoring method, national agricultural research policy objectives are converted into measurable weighted scores. The agricultural development objectives for Uganda were identified as follows (op. cit. Vol. 2, p. 4.):

(a) ensuring the supply of adequate and balanced food in all parts of the country at all times;
(b) ensuring the supply of raw materials to meet the needs of the local industries;
(c) stimulating production for export and for import substitution;
(d) raising producer incomes and improving the quality of life in general;
(e) conserving the natural resource base of the country (soil, water, forests, fish, and other resources) and attaining sustainable productivity of the agricultural sector.

These national objectives were then converted into measurable criteria for priority setting and weighted. This weighted scoring system was then applied to the various commodities to arrive

[19] For a detailed analysis of the advantages and disadvantages of the alternative priority setting methods see Norton and Pardy (1987, pp. 2-6) and Bottomley and Contant (1988, pp. 9-14).

at a numerical score which could be ranked ordinally and then divided into three priority classes: high, medium, and low.[20]

The results of this exercise as it applied to the five commodities under consideration in this study are summarized in table 7. These rankings are compared to the rate of return which was calculated for each commodity using both the base case and worst case scenarios.

Table 7. Comparative Research Priority Rankings Using the Weighted Scoring Method and Benefit-Cost Analysis

COMMODITY	WEIGHTED SCORING METHOD RANK	NARO PRIORITY LEVEL	ROR BASE CASE SCENARIO	ROR WORST CASE SCENARIO
Groundnuts	5	high	37.1%	23.1%
Maize	7	high	33.2%	27.3%
Sesame	15	medium	42.5%	15.3%
Soybeans	18	low	4.8%	-6.0%
Sunflower	20	low	38.4%	10.3%

These results show that the base case scenario ROR for both sesame and sunflower exceeds that of maize and groundnuts. There are a number of factors which contribute to this difference in rankings. First of all, the weighted scoring method placed heavy emphasis on the average value of production of the commodity over the preceding 3 years (1987-89). This immediately gives an edge to basic food staples and traditional cash crops. Both sesame and sunflower are minor crops but ones whose area has expanded considerably in recent years in response to market opportunities. This more recent expansion is captured in the ROR analysis but not in the weighted scoring.

Secondly, the weighted scoring system gave specific consideration to the number of farmers whose income would be raised by improving yields of that commodity (as a proxy for equity) and to the environmental impact of the technical change. These are subjective measures[21] which

[20] For a detailed description of the weighted scoring system applied in Uganda see Republic of Uganda, Volume 2 (1991), pp. 2-22.

[21] The values were obtained from interviews and their exact interpretation is unclear.

are not considered in the ROR analysis. By not considering these factors the ROR analysis implicitly assumes that economic efficiency is the only objective being maximized.[22]

Thirdly, no specific measure of foreign exchange earnings/savings was included in the weighted criteria even though this is an important national agricultural objective. The ROR analysis, on the other hand, is an economic analysis which uses shadow exchange rates to reflect the true scarcity value of foreign exchange. This would tend to enhance the value of exported or import-substituting commodities over those for purely national consumption.

Lastly, the weighted scoring method gives no specific attention to either the timing or the cost of the research while the ROR is a dynamic analysis which emphasizes both of these factors. The ROR explicitly compares the time-valued estimate of the net returns from the adoption of research results with the time-valued costs of the research itself. "It thus reflects the fact that events occur sequentially, even if their magnitude cannot always be accurately predicted. The changing value of variables over time, and their changing relations to one another, are at least taken into account (Bottomley and Contant 1989, p. 85)." The balance between the time value of costs and benefits is tested, using sensitivity analysis, to identify those factors which have the greatest impact on the ROR. For both sesame and sunflower, changes in the timing of adoption have a major impact on the expected returns. This is reflected in the large difference between the base case scenario and the worst case results.[23] Sunflower returns will be highly dependent on what happens in the marketing and price of the commodity and the resultant adoption by farmers. The rate of return to sesame research, on the other hand is most affected by the potential for delay in the release of research results. A two year delay in the release of the improved variety reduces the ROR by nearly two thirds.

4.2. The Advantages and Disadvantages of Alternative Priority-Setting Methods

The simplest priority-setting system to set in place is that of checklists. Some experts advise that it is best for systems with no priority-setting experience to start with these simpler tools and then move into scoring methods when the expertise to help determine weights and values becomes available.

Such checklists and scoring methods tend to be preferred by priority setters and planners at least initially. They are more transparent and readily understandable, even though they are also more subjective. What is important is that the methods be improved continually by a growing

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[22] Theoretically, it is possible to design a system of weights for including such considerations into an ROR analysis, but this was not done in the case of Uganda due to lack of data.

[23] Bottomley and Contant recommend that in cases of considerable uncertainty the ROR be specifically calculated using both optimistic and pessimistic assumptions. "If under pessimistic assumptions the results still indicate a high priority, then it would be reasonable to accord it that, in spite of all the uncertainties" (1988, p. 86). The case of sesame and sunflower is less clear cut since under the most pessimistic assumptions the ROR falls to low, but acceptable, levels.

understanding of the relative importance of the different factors underlying the benefits and costs of agricultural research. This is where the investment in more detailed benefit-cost analysis fits in.

Benefit-cost analyses are used frequently in project appraisals of all sorts. For this reason, they employ a logic and language with which policy makers are familiar. One problem, however, is that because of their complexity there is a tendency for researchers and policy makers to view them as a black box. They feed in a mass of data and the "correct answer" miraculously pops out of the other end. To achieve its greatest impact, the process requires a great deal of interaction and dialogue between the analyst and the research community. Properly conducted, however, benefit-cost analysis has the advantage of compelling the planner to take into account the anticipated sequence of events and their magnitude.

The ROR analysis subsumes a large array of variables into a manageable number of indicators.[24] It integrates both scientific and economic variables into the priority-setting process in a consistent and systematic manner. These variables include (a) the quantity of specific commodities produced and consumed, (b) commodity prices and any distortions due to price policies, (c) the price responsiveness of supply and demand, (d) the time value of money, (e) the cost of research, (f) the probability of success of the research program, (g) the expected output enhancing or costs reducing effects of the research over time, and (h) the expected rate and spread of technology adoption.

Even where national data bases are not advanced, ROR analysis can still provide valuable insights as long as expertise is available to make sensible hypotheses. The advantage of conducting even a few ex-ante benefit-cost studies is that, through sensitivity analysis, they help to reveal which factors have the greatest impact on the returns to research. Its application can then stimulate greater efforts to collect the relevant data for future analyses. In this way they add to the stock of knowledge. When they are later followed up by ex-post ROR analyses, we can then begin to build up a much better understanding of how innovations behave within a given farming system and socio-economic environment. A reasonably reliable set of principles should begin to emerge which decision makers can take into consideration even when using subjective judgment to made decisions.

The major disadvantage of relying exclusively on ROR analysis for priority setting, however, is that such analysis biases the research system against subject matter research (including socio-economics) which does not easily lend itself to ex-ante benefit-cost analysis but is clearly essential as a complement to commodity research. Hence the need for a blend of priority-setting mechanisms used intelligently by experienced researchers and administrators.

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[24] ROR analysis assumes two agricultural research goals, raising the national income (efficiency) and equity in terms of the distribution of benefits between producers and consumers. A procedure similar to that for soliciting weights for the weighted scoring model can be used to determine the relative emphasis on each. When only the ROR is used to rank research investments, all of the weight is being implicitly placed on the efficiency objective.

5. CONCLUSIONS AND OUTSTANDING ISSUES

The ROR analysis for groundnuts and sesame confirms the overall conclusion of the earlier ROR study of maize, soybeans, and sunflower. Even in Uganda, with its history of political instability, the potential returns to agricultural research are excellent. This is true even when the high costs of physical rehabilitation, training, and extension are included.

The returns to groundnuts and sesame greatly surpass those reported for soybeans and are less uncertain than those of sunflower. A number of factors contribute to this. First, the area planted in the traditional oilseeds far exceeds that in soybeans and sunflower. This increases the potential for large scale national benefits.

Secondly, the markets for these commodities are better established. They are highly valued on the domestic market and the export market for sesame has been flourishing in recent years. Neither commodity faces the kind of downward international price pressure exhibited in sunflower. Ugandan groundnuts cannot compete with American peanuts, which are subsidized by the existing system of price supports. As long as production serves primarily the domestic market, however, the high cost of transportation shields the Ugandan producer. The potentially high returns to both sesame and sunflower, which had been ranked as lower priority commodities by the earlier weighted scoring exercise, illustrates the importance of considering not only domestic food production needs, but also market potential and foreign exchange earnings. The instability of these returns, however, highlights the importance of price and marketing policy as well as specific issues directly related to research productivity.

Despite the high, potential ROR to investments in oilseeds research, Uganda is still plagued by various constraints that inhibit adoption of new technology and the achievement of significant future research results. Macro-level constraints on the productivity and sustainability of the research system have not yet been fully overcome. The Ugandan government's inability to raise sufficient tax revenues to finance an adequate program of investment in the agricultural sector leaves the fate of agricultural research largely in the unpredictable hands of donors. Perhaps most corrosive to research productivity has been the uncertainty and lack of control over operating funds. The Groundnut and Sesame Subproject of the World Bank funded Headstart for Agricultural Research and Extension Project received only 8.5 million USh out of the nearly 72 million USh that it was budgeted to receive by the end of 1992. This shortfall in funds is primarily the result of the Ugandan government's inability to advance money for research which can later be submitted for World Bank reimbursement. In all likelihood this funding has been completely lost and will not be recoverable even if the flow of funds improves in the future under the financial management of NARO.[25] It is very difficult for researchers to develop and implement an efficient and productive research program under such conditions. Continuity of funding is absolutely essential to the achievement of the research impact predicted by the ROR analysis. This is particularly the case with respect to sesame research.

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[25] Based on information provided in Busolo-Bulafu (1992) and personal communication with Professor Okedi, HARE Project Director.

Major effort is still required to establish an efficient and financially viable system of seed multiplication and distribution, without which new varieties will simply sit moldering on the shelf. Past government interventions have distorted the input supply sector, undermining the economic base, and deterring the private sector from responding to the farm level demand for goods and services.[26] These distortions are gradually being dismantled, but further effort is required to promote the efficient operation of a competitive private sector.

Priority setting is not a once-and-for-all accomplished fact. Continued dialog and reassessment are required in order to maximize our understanding of the research system and its impact on the agricultural sector. Only then can an effective mechanism for research planning and management be established which is responsive to the changing physical and economic environment.

The ROR analyses for maize, soybeans, sunflower, sesame, and groundnuts have pointed out a number of important issues which need to be addressed. One key factor is the need for better data collection in order to document the performance of new technologies under farmer conditions and to map the extent and spread of adoption. Virtually no information currently exists concerning on-farm yields and variety adoption. Better data collection will need to be a key component of future research impact monitoring. This information will then feed into making more realistic estimates for future ex-ante projections.

The analyses highlight the importance of marketing and technology transfer systems which are external to the research system itself but greatly affect its potential impact. Subsector analysis, which takes a broad look at the constraints from production through to consumption, has been recommended for key commodities. Such information will help to identify the key areas for policy consideration.

[26] For a detailed discussion see Laker-Ojok 1993b.

APPENDICES

APPENDIX 1. THE PROJECTION OF ADOPTION CURVES BASED ON HISTORICAL SEED SALES

The logistic growth function is the formulation commonly used to represent the diffusion path of innovations over time. The logistic function is an `S'-shaped curve characterized as follows:

$$P(t) = K/[1+e^{-(a+bt)}]$$

In this equation `P' represents the cumulative growth in the proportion of area for that commodity which is produced using the innovation; `K' is the long run upper limit on diffusion (the adoption ceiling); `b' is the slope of the curve and represents a measure of the rate of acceptance of the new technology; and the intercept `a' reflects aggregate adoption at the start of the estimation period and positions the curve on the time line. Griliches (1957) used this logistic function to describe the diffusion of hybrid corn in the United States.

The estimation of these three parameters which define the expected diffusion path is conducted in two steps. First historical data on the sale of improved seeds from the Uganda Seed Scheme during the 1970s are used to estimate the parameters of the diffusion path which occurred in these commodities in the past. The diffusion parameters are estimated with an ordinary least-squares (OLS) regression, using a logistic function of the form discussed above. Because diffusion was cut off by the political insecurity of the 1980s, total diffusion and the date at which the ceiling would have been achieved are forecasted using the estimated diffusion parameters. The level of `K' (which represents the diffusion ceiling) which results in the best fitting regression equation determines which set of parameters is selected for each commodity.

Secondly this adoption curve is used to project the percent of area planted to each commodity which will be produced using the newly released varieties for each of the next 15 years. Alternative adoption ceilings are then selected to alter the assumed diffusion path for purposes of the sensitivity analysis. Table 8 gives the parameters for the best fitting diffusion path for each of the four commodities estimated in the course of this study.

The shape of each alternative diffusion path was illustrated in figure 1 in the main body of the text.

In the case of sesame, alternative scenarios were run using each of these diffusion paths. The ROR results clearly indicate the impact of using an adoption path with a higher intercept or a steeper slope. The diffusion path for maize actually has the highest adoption ceiling. Its lower intercept and more gradual slope, however, result in lower benefits in the initial years than does a steeper adoption curve such as that for sunflower. This is true even though the final adoption ceiling is lower for sunflower. The ROR calculation discounts benefits more the farther they are into the future. As a result, the diffusion path with the more gradual slope results in a lower net benefit stream.

Table 8. Estimated Parameters for Maize, Soybeans, Sunflower, and Groundnuts

ESTIMATED PARAMETER	MAIZE	SOYBEANS	SUNFLOWER	GROUNDNUTS
Ceiling	59%	71%[a]	32%	22%
Origin	2.163	5.722	7.252	3.398
Slope	.44	.55	2.07	.38
Adjusted R squared	.94	.93	.99	.88

[a] The best fitting value of K (the adoption ceiling) for soybeans was actually 71%. This is the value which generated the origin, slope, and R^2 values indicated. This ceiling was cut in half, however, under the assumption that the newly released variety would only be likely to replace half of the area currently planted to the previously released variety.

For sesame, the diffusion path for soybeans was taken as the base case scenario. The soybean curve lies intermediate between the more gradual curves for groundnuts and maize, and the steeper curves for sunflower and the NARO estimate.

APPENDIX 2. ROR TO GROUNDNUT RESEARCH AND EXTENSION

Table 9A. The Rate of Return to Groundnut Research and Extension in Uganda: The Base Case Scenario (1985-91)

Valued at 1992 domestic price of 400. Including extension costs, rehabilitation, and training assuming release of new variety in 1993 and distribution to farmers beginning 1995.

Category	1985	1986	1987	1988	1989	1990	1991
BENEFITS without Research							
Area in local vars. (ha)	137,000	177,000	148,000	179,000	189,000	186,000	180,000
Yield, local varieties (kg shelled gnuts/ha)	450	450	450	450	450	450	450
Production (t)	61,650	79,650	66,600	80,550	85,050	83,700	81,000
Domestic price, local varieties ('000 USh/t)	7	19	53	151	284	297	332
Prod. value (mill. USh) (1)	452	1,520	3,499	12,128	24,154	24,859	26,892
BENEFITS with Research							
Area in local vars. (ha)	137,000	177,000	148,000	179,000	189,000	186,000	180,000
Yield, local varieties (kg shelled gnuts/ha)	450	450	450	450	450	450	450
Prod. local vars. (t)	61,650	79,650	66,600	80,550	85,050	83,700	81,000
Domestic price, local varieties ('000 USh/t)	7	19	53	151	284	297	332
Prod. value, local vars. ('000,000 USh) (2)	452	1,520	3,499	12,128	24,154	24,859	26,892
Area in imp. varieties	0	0	0	0	0	0	0
Yield, improved vars. (kg shelled gnuts/ha)	0	0	0	0	0	0	0
Prod., impr. vars. (t)	0	0	0	0	0	0	0
Domestic price, impr. vars. ('000 USh/t)	7	19	53	151	284	297	332
Prod. value, impr. vars. ('000,000 USh) (3)	0	0	0	0	0	0	0
Add'l. benefit (4=3+2-1)	0	0	0	0	0	0	0
COSTS with Research							
Incremental production costs ('000,000 USh) (5)	0	0	0	0	0	0	0
Research and extension costs ('000,000 USh) (6)	0.7	1.5	2.8	8.4	18.2	27.5	35.4
Total additional costs (7=5+6)	0.7	1.5	2.8	8.4	18.2	27.5	35.4
NET BENEFIT (8=4-7)	-0.7	-1.5	-2.8	-8.4	-18.2	-27.5	-35.4
REAL NET BENEFIT (8/deflator)	-33	-28	-17	-17	-20	-22	-23

Table 9B. The Rate of Return to Groundnut Research and Extension in Uganda: The Base Case Scenario (1992-98)

Category	1992	1993	1994	1995	1996	1997	1998
BENEFITS without Research							
Area in local varieties (ha)	180,000	180,000	180,000	180,000	180,000	180,000	180,000
Yield, local varieties (kg shelled gnuts/ha)	450	450	450	450	450	450	450
Production (t)	81,000	81,000	81,000	81,000	81,000	81,000	81,000
Domestic price, local varieties ('000 USh/t)	400	400	400	400	400	400	400
Prod. value ('000,000 USh) (1)	32,400	32,400	32,400	32,400	32,400	32,400	32,400
BENEFITS with Research							
Area in local varieties (ha)	180,000	180,000	178,152	177,352	176,240	174,728	172,731
Yield, local varieties (kg shelled gnuts/ha)	450	450	450	450	450	450	450
Production, local varieties (t)	81,000	81,000	80,168	79,808	79,308	78,627	77,729
Domestic price, local varieties ('000 USh/t)	400	400	400	400	400	400	400
Prod. value, local vars. ('000,000 USh) (2)	32,400	32,400	32,067	31,923	31,723	31,451	31,092
Area in improved varieties	0	0	1,848	2,648	3,760	5,272	7,269
Yield, improved vars. (kg shelled gnuts/ha)	0	0	780	780	780	780	780
Prod., impr. vars. (t)	0	0	1,442	2,066	2,933	4,112	5,670
Domestic price, impr. vars. ('000 USh/t)	400	400	400	400	400	400	400
Prod. value, impr. vars. ('000,000 USh) (3)	0	0	577	826	1,173	1,645	2,268
Add'l. benefit (4=3+2-1)	0	0	244	350	496	696	960
COSTS with Research							
Incremental production costs ('000,000 USh) (5)	0	0	65	28	39	53	70
Research and extension costs ('000,000 USh) (6)	52.5	58.6	80.5	62.7	43.6	43.6	43.6
Total additional costs (7=5+6)	52.5	58.6	145.2	90.7	82.5	96.5	113.5
NET BENEFIT (8=4-7)	-52.5	-58.6	98.8	258.9	413.8	599.4	846.0
REAL NET BENEFIT (8/deflator)	-34	-37	63	165	264	383	540

Table 9C. The Rate of Return to Groundnut Research and Extension in Uganda: The Base Case Scenario (1999-2006)

Category	1999	2000	2001	2002	2003	2004	2005	2006
BENEFITS without Research								
Area in local varieties (ha)	180,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000
Yield, local vars. (kg/ha)	450	450	450	450	450	450	450	450
Production (t)	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000
Domestic price vars. ('000 USh/t)	400	400	400	400	400	400	400	400
Prod. value (mill./USh) (1)	32,400	32,400	32,400	32,400	32,400	32,400	32,400	32,400
BENEFITS with Research								
Area in local varieties (ha)	170,194	167,125	163,622	159,884	156,169	152,728	149,743	147,298
Yield, local vars. (kg/ha)	450	450	450	450	450	450	450	450
Production, local vars. (t)	76,587	75,206	73,630	71,948	70,276	68,727	67,384	66,284
Price, local vars. ('000 USh/t)	400	400	400	400	400	400	400	400
Prod. value, local vars. (mill. USh) (2)	30,635	30,082	29,452	28,779	28,110	27,491	26,954	26,514
Area improved varieties	9,806	12,875	16,378	20,116	23,831	27,272	30,257	32,702
Yield improved vars. (kg/ha)	780	780	780	780	780	780	780	780
Prod impr. vars.	7,649	10,043	12,775	15,690	18,588	21,272	23,600	25,507
Price impr. vars. ('000USh/t)	400	400	400	400	400	400	400	400
Prod. value impr. vars. (mill./USh)	3,059	4,017	5,110	6,276	7,435	8,509	9,440	10,203
Add'l. benefit	1,294	1,700	2,162	2,655	3,146	3,600	3,994	4,317
COSTS with Research								
Prod. costs (mill./USh) (5)	89	107	123	131	130	120	104	86
Research/exten. costs (mill./USh)	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6
Total costs	132.4	151.0	166.2	174.4	173.6	164.0	148.1	129.2
NET BENEFIT	1,162.0	1,548.5	1,995.7	2,480.8	2,972.1	3,435.9	3,845.9	4,187.5
REAL NET BENEFIT	742	989	1,274	1,584	1,898	2,194	2,456	2,674
REAL IRR (%) ====>	37.1%	IF CUT OFF IN 2006						
REAL IRR (%) ====>	32.6%	IF CUT OFF IN 2006						
REAL IRR (%) ====>	12.1%	IF CUT OFF IN 1996						

APPENDIX 3. ROR TO SESAME RESEARCH AND EXTENSION

Table 10A. The Rate of Return to Sesame Research and Extension in Uganda: The Base Case Scenario (1985-91)

Including extension costs, rehabilitation, and training, assuming release of new variety in 1994 and distribution to farmers beginning 1995. Uses adoption curve projected for soybeans.

Category	1985	1986	1987	1988	1989	1990	1991
BENEFITS without Research							
Area in local varieties (ha)	76,000	80,000	74,000	81,000	92,000	124,000	130,000
Yield, local varieties (kg)	400	400	400	400	400	400	400
Production (t)	30,400	32,000	29,600	32,400	36,800	49,600	52,000
Export price, local varieties ('000 USh/t)	4.05	10	31	76	156	188	308
Prod. value ('000,000 USh) (1)	123	320	903	2,456	5,741	9,325	16,016
BENEFITS with Research							
Area in local varieties (ha)	76,000	80,000	74,000	81,000	92,000	124,000	130,000
Yield, local varieties (kg)	400	400	400	400	400	400	400
Production, local varieties (t)	30,400	32,000	29,600	32,400	36,800	49,600	52,000
Export price, local varieties ('000 USh/t)	4	10	31	76	156	188	308
Prod. value, local vars. ('000,000 USh) (2)	123	320	903	2,456	5,741	9,325	16,016
Area in improved varieties	0	0	0	0	0	0	0
Yield, improved vars. (kg)	0	0	0	0	0	0	600
Prod., impr. vars. (t)	0	0	0	0	0	0	0
Export price, impr. vars. ('000 USh/t)	4	10	31	76	156	188	308
Prod. value, impr. vars. ('000,000 USh) (3)	0	0	0	0	0	0	0
Add'l. benefit (4=3+2-1)	0	0	0	0	0	0	0
COSTS with Research							
Incremental production costs ('000,000 USh) (5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Research and extension costs ('000,000 USh) (6)	0.9	1.7	3.0	10.5	13.5	19.8	54.3
Total additional costs (7=5+6)	0.9	1.7	3.0	10.5	13.5	19.8	54.3
NET BENEFIT (8=4-7)	-0.9	-1.7	-3.0	-10.5	-13.5	-19.8	-54.3
REAL NET BENEFIT (8/deflator)	-42	-32	-19	-22	-15	-16	-35

Table 10B. Estimation of the Rate of Return to Sesame Research and Extension in Uganda (1992-98)

Including extension costs, rehabilitation, and training, assuming release of new variety in 1994 and distribution to farmers beginning 1995. Uses adoption curve projected for soybeans.

Category	1992	1993	1994	1995	1996	1997	1998
BENEFITS without Research							
Area in local varieties (ha)	130,000	130,000	130,000	130,000	130,000	130,000	130,000
Yield, local varieties (kg)	400	400	400	400	400	400	400
Production (t)	52,000	52,000	52,000	52,000	52,000	52,000	52,000
Export price, local varieties ('000 USh/t)	335	553	553	553	553	553	553
Prod. value ('000,000 USh) (1)	17,420	28,748	28,748	28,748	28,748	28,748	28,748
Benefits with Research							
Area in local varieties (ha)	130,000	130,000	130,000	123,104	120,111	116,281	111,729
Yield, local varieties (kg)	400	400	400	400	400	400	400
Production, local varieties (t)	52,000	52,000	52,000	49,241	48,044	46,513	44,692
Export Price, local varieties ('000 USh/t)	335	553	553	553	553	553	553
Prod. value, local vars. ('000,000 USh) (2)	17,420	28,748	28,748	27,223	26,561	25,714	24,708
Area in improved varieties	0	0	0	6,896	9,889	13,719	18,271
Yield, improved vars. (kg)	600	600	600	600	600	600	600
Prod., impr. vars. (t)	0	0	0	4,138	5,933	8,231	10,962
Export price, impr. vars. ('000 USh/t)	335	553	553	553	553	553	553
Prod. value, impr. vars. ('000,000 USh) (3)	0	0	0	2,288	3,280	4,551	6,061
Add'l. benefit (4=3+2-1)	0	0	0	763	1,093	1,517	2,020
COSTS with Research							
Incremental production costs ('000,000 USh) (5)	0.0	0.0	0.0	1.1	0.5	0.6	0.8
Research and extension costs ('000,000 USh) (6)	90.2	54.8	76.7	58.9	41.7	41.7	41.7
Total additional costs (7=5+6)	90.2	54.8	76.7	60.1	42.2	42.3	42.5
NET BENEFIT (8=4-7)	(90.2)	(54.8)	(76.7)	702.5	1,051.2	1,474.5	1,977.7
REAL NET BENEFIT (8/deflator)	(58)	(35)	(49)	449	671	941	1,263

Table 10C. Estimation of the Rate of Return to Sesame Research and Extension in Uganda (1999-2006)

Category	1999	2000	2001	2002	2003	2004	2005	2006
				BENEFITS without Research				
Area in local varieties (ha)	130,000	130,000	130,000	130,000	130,000	130,000	130,000	130,000
Yield, local varieties (kg)	400	400	400	400	400	400	400	400
Production (t)	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
Export price, local vars. ('000 USh/t)	553	553	553	553	553	553	553	553
Prod. value (mill. USh) (1)	28,748	28,748	28,748	28,748	28,748	28,748	28,748	28,748
				BENEFITS with Research				
Area in local varieties (ha)	106,771	101,858	97,425	93,753	90,918	88,847	87,395	86,406
Yield, local varieties (kg)	400	400	400	400	400	400	400	400
Production, local varieties (t)	42,708	40,743	38,970	37,501	36,367	35,539	34,958	34,562
Export price, local vars. ('000 USh/t)	553	553	553	553	553	553	553	553
Prod. value, local vars. (mill. USh) (2)	23,611	22,525	21,544	20,732	20,105	19,648	19,326	19,108
Area in improved varieties	23,229	28,142	32,575	36,247	39,082	41,153	42,605	43,594
Yield, improved vars. (kg)	600	600	600	600	600	600	600	600
Prod. impr. vars. (t)	13,937	16,885	19,545	21,748	23,449	24,692	25,563	26,156
Export price, impr. vars. ('000 USh/t)	553	553	553	553	553	553	553	553
Prod. value, impr. vars. (mill. USh) (3)	7,705	9,335	10,805	12,024	12,964	13,651	14,132	14,460
Add'l. benefit (4=3+2-1)	2,568	3,112	3,602	4,008	4,321	4,550	4,711	4,820
				COSTS with Research				
Add'l. production costs (mill. USh) (5)	0.8	0.8	0.7	0.6	0.5	0.3	0.2	0.2

Research and ext. costs (mill. USh) (6)	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7
Total additional costs (7=5+6)	42.5	42.5	42.4	42.3	42.2	42.1	42.0	41.9
NET BENEFIT (8=4-7)	2,525.9	3,069.1	3,559.3	3,965.5	4,279.1	4,508.2	4,668.8	4,778.3
REAL NET BEN. (8/deflator)	1,613	1,960	2,273	2,532	2,732	2,878	2,981	3,051
REAL IRR (%) ====>	42.5%	IF CUT OFF IN 2006						
REAL IRR (%) ====>	39.8%	IF CUT OFF IN 2001						
REAL IRR (%) ====>	21.1%	IF CUT OFF IN 1996						

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