Journal of Stored Products Research 47 (2011) 147–156

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Review

The economic impact of cowpea research in West and Central Africa: A regional impact assessment of improved cowpea storage technologies

B. Moussa [a,*], J. Lowenberg-DeBoer [a], J. Fulton [a], K. Boys [b]

[a] Department of Agricultural Economics, Purdue University, Krannert Building, West Lafayette, IN 47907, United States
[b] Department of Applied Economics and Statistics, Clemson University, Barre Hall, Clemson, SC 29625, United States

ARTICLE INFO

Article history:
Accepted 16 February 2011

Keywords:
Cowpea
Storage
Technology
Impact assessment
Africa

ABSTRACT

Researchers from the Bean/Cowpea Collaborative Research Support Program (CRSP), a program supported by the USAID, developed several non-chemical cowpea grain storage technologies in the 1980s. These included hermetic storage in airtight containers, improved ash storage, and the solar heater. Impact studies conducted at the country level showed that the research program was economically a good investment. As the CRSP new storage technologies spread throughout West and Central Africa, a regional assessment including spillover effects became necessary to fully comprehend the impact and guide future research investments. Therefore, this study sought to measure the economic impact of the new CRSP cowpea storage technologies at a regional level. Surveys in seven countries were used to estimate storage technology adoption. Economic surplus was used to estimate annual benefits and internal rate of return (IRR), and net present value (NPV) were calculated to summarize the net benefits. From the perspective of recipients' countries the project was a good investment. The IRR, is found to be much greater than the cost of capital. The regional IRR was found to be about 29%, much higher than the real interest rate on government bonds in West Africa at the time. For example the real interest rate on bonds issued by the government of Ghana in 2004 and 2005 was 8.9% and 5.4% respectively. The IRR is also higher than the private bank real lending rates in West Africa. From the perspective of the principal donor, the US government, the project was a good investment given that the average real interest rate on US government's bonds was 4.8% during the period. The net present value of the investment amounts to more than 295 million US dollars which yields an annualized value of about 17 million.

1. Introduction

Storage of cowpea is a challenge for farmers in West and Central Africa. Cowpea grain is infested both in the field and in storage by insect pests. These pests degrade the nutritional quality and economic value of the grain. Because of pests producers often sell at the low harvest prices to avoid storage losses. In West and Central Africa, several methods are traditionally used to store grain, the choice among which is dependent on many factors such as the type and value of the grain, the duration of storage, the climate, the cost and availability of labor. Schulz (1993) identified several techniques that were used to store grains including on platforms, different types of granaries (plant materials, clay, and mud), bins, airtight underground pits, baskets, jars, and in woven bags. Some of these traditional methods are effective under some circumstances. The ash method for example works well but only with small quantities of cowpea. For large quantities of cowpea this technique cannot be used because the quantity of ash necessary would not be available.

This storage problem needs to be addressed in order for the farmers to realize the potential economic and nutritional advantages offered by production of cowpea grain.

Cowpea (*Vigna unguiculata* (L.) Walpers) is the most economically important indigenous African legume crop. Worldwide, an estimated 3.7 million metric tonness of cowpea is produced annually on about 8.7 million hectares (Langyintuo et al., 2003). About 87% of that area is in Africa, 10% in the Americas, and the rest in Europe and Asia. This grain is used throughout semi-arid sub-Saharan Africa as a food source. Cowpeas can provide a relatively inexpensive source of high quality protein for both humans and animals, and its leaves and stems are fed to cattle. In addition, although local varieties often have low yields (200–350 kg/ha; Schulz, 1993), cowpeas offer important benefits to its producers who are often income and resource poor. As a legume, cowpeas fix nitrogen into the soil and, in doing so, reduce the need to buy costly

* Corresponding author. Tel.: +1 765 494 4305; fax: +1 765 494 9176.
E-mail address: bmoussa@purdue.edu (B. Moussa).

0022-474X/$ – see front matter
doi:10.1016/j.jspr.2011.02.001

fertilizers. Cowpeas are relatively drought tolerant and thus offer farmers a means to reduce their exposure to weather risk.

Cowpeas contribute to the food security of farmers in several ways. Cowpeas can be consumed directly by farm families, sold for cash to buy other necessities, or kept as seed for the following year. When cowpea grain is sold at harvest, due to the relative abundance of the grain on the market at that time, farmers usually receive a low price. From the producer perspective then, it would be preferable to store grains for some time to take advantage of market price increases which come in the weeks and months following harvest. Due to the lack of good storage techniques and the pressing need for cash this is frequently not possible.

Recognizing the important role of cowpeas in the livelihood and wellbeing of low income farmers, the U.S. Agency for International Development (USAID) funded the Bean/Cowpea Collaborative Research Support Program (CRSP). From1982–2007, this program formalized and supported research and extension linkages between West and Central African cowpea researchers and their U.S. counterparts. Early in its history, the Bean/Cowpea CRSP identified post-harvest insect pests as an important constraint to cowpea marketing, trade and utilization. In Senegal, CRSP research efforts helped to develop a technique of hermetic storage of cowpea grain in recycled metal drums as a non-chemical alternative to traditional storage methods. Research in Cameroon generated three storage technologies: a solar heater, an improved ash storage technique, and a triple bagging technique.

Hermetic storage of grain is an ancient practice. Respiration by insects in sealed storage uses up oxygen and generates anaerobic conditions which limit infestation. The contribution of CRSP researchers was to identify locally available containers which could be used for the hermetic storage of cowpea grain, and to determine the conditions under which this storage is effective. In the case of Senegal, through collaboration with the Food Technology Institute (ITA) and the Senegalese Institute for Agriculture Research (ISRA), metal drums were identified as appropriate grain storage containers. These drums may be hermetically sealed and, as they are imported as shipping containers for liquid products (e.g. sugar, petroleum derivatives), are widely available.

In most other West and Central African nations, drums have higher priority uses such as hauling and storing water. In seeking other storage alternatives, studies by researchers at the Institute of Agricultural Research for Development (IRAD) in Cameroon and Purdue University determined that putting infested grains in airtight, heavy duty, plastic bags is sufficient to arrest cowpea bruchid infestation (Murdock et al., 2003). At least two plastic layers were found to be required because some bruchids may pierce the inner plastic layer; this is particularly the case if the bruchids emerge from grains lying directly against the plastic. With this storage technique, an outer bag of woven jute or polypropylene may also be used to protect the plastic bags and facilitate handling. In practice, "triple bagging" has come to refer to the combination of two inner polyethylene bags and an outer woven jute or polypropylene bag, and "double bagging" refers to the use of one inner polyethylene bag and an outer woven bag. The triple bagging technology was initially developed and disseminated; double bagging is a farmer adaptation of the triple bagging technique.

A third CRSP storage innovation was the enhancement of the ash storage technique. To help protect grain from insect damage, traditionally many farmers in sub-Saharan Africa mix their cowpea grain with sieved ash from cooking fires. This ash storage technique works by creating a physical barrier to insect movement and reproduction (Murdock et al., 2003). CRSP scientists at Purdue found an optimal way to use this method. After experimenting with different proportions of ash to grain, they recommended that equal volumes of sieved ash and cowpea grain be mixed, placed in a container and covered by a 3 cm layer of ash. While this technique is effective, its use is constrained by the limited quantities of available ash, and the fact that some cultures consider ashes to be "dirty" and people will not eat food which has been stored in ashes.

A final innovation is the development of a simple solar heater that can be used to kill cowpea bruchids and larvae prior to storage. This technique was developed in Cameroon in collaboration with IRAD. This process consists of exposing a thin layer of cowpeas (usually two or three grains deep) to sunlight in a simple solar heater made of a black plastic sheet spread on a layer of dry grass or other insulating material, covered with a clear plastic sheet folded on the edges to retain heat. Exposure to tropical sunlight for two hours is usually sufficient to kill any insects or larvae which are present (Murdock and Shade, 1991). After treatment, it is required that the cowpea grain be stored in a container sealed to prevent recontamination.

To date, efforts to assess the impact of these technologies have been limited to specific studies in countries where the technologies were initially developed and disseminated. Faye and Lowenberg-DeBoer (1999) evaluated CRSP technology adoption in Senegal and estimated an internal rate of return (IRR) of 9% for the drum storage technology. More recently, Boys et al. (2007) demonstrated that in Senegal the use of the metal drum storage technology generated an IRR of 12.1% annually.

The regional benefits of investment in cowpea storage research, however, are unknown. In addition to extension efforts by CRSP partner organizations, these storage technologies have been widely disseminated throughout West and Central Africa. Non-governmental organizations (NGOs) and the International Institute for Tropical Agriculture (IITA), cowpea focused projects like the Protection Ecologiquement Durable du Niébé (PEDUNE) and the Project for Cowpeas in Africa (PRONAF), as well as other development projects participated in disseminating these technologies in other cowpea producing countries. Given the large geographic area in which cowpea grain is produced and traded, and the wide dissemination of these technologies, to assess the full impact of this program it is necessary to conduct a regional impact assessment which includes technology spillover effects. This information is also needed to help guide future investment in agricultural research in general, and in post-harvest research in particular.

The purpose of this study is to measure the economic impact of the non-chemical CRSP cowpea storage technologies in West and Central Africa. Unlike previous analyses which examined the impact of CRSP technologies in the countries where they were developed and introduced, this study examines the impact of these technologies throughout the region where they have been disseminated. In this analysis, data from the nations of Benin, Burkina Faso, Cameroon, Mali, Niger, Nigeria and Senegal were collected and analyzed. Together these countries produce more than 96% of cowpea produced in the West and Central African region.

2. Methodology

Several alternative methodological approaches may be used to evaluate the economic impact of the CRSP improved storage technologies (Alston et al., 1995; Masters et al., 1996). The approach used in this study was organized as two separate steps. First, surveys were used to collect information from cowpea producers in each of the examined countries. Results of these surveys, combined with information collected from secondary data sources, were then used to generate data inputs and parameters required to conduct a regional economic impact assessment.

For this analysis, the social benefit generated through the improved CRSP technologies was estimated using the economic surplus method. This approach offers several analytical advantages which are particularly relevant to this topic. Important also given the broad geographic scope of this study, the economic surplus approach is less data intensive than alternative assessment methods. An econometric approach can also be used for impact assessment but it usually requires time series data on the technology and crop. In this case, these data are not available. Programming models are another approach but require information on production and marketing that is not uniformly available in all the countries.

As the economic surplus approach is among the most common approaches for analyzing the welfare effects of agricultural research, it will only be described briefly here. The economic surplus approach estimates the return to an investment by calculating the change in 'social wellbeing' (e.g. consumer and producer benefit or surplus) that is generated due to the introduction of a new technology (Alston et al., 1995; Masters et al., 1996). This approach requires that the (positive) impact of adopting the technology be compared against the investment required to develop and disseminate it. The difference between these benefits and costs reflects the net benefit of the technology.

Estimates of consumer and producer surplus have been demonstrated to be sensitive to parameter assumptions. Evidence suggests that measures of total surplus are more robust in the face of limited information (particularly information on demand and supply elasticities) than the disaggregated consumer and producer surplus (Alston et al., 1995). As it is the intent of this study to holistically measure the impact of these storage technologies, this study will focus on measures of total economic surplus.

Theoretically, the economic surplus approach assumes that the demand curve is an accurate measure of the potential benefit to consumers, and that the supply curve reflects the cost to producers of generating a particular good. As such, among the key advantages of this approach is that it accounts for both price and quantity changes induced by the adoption of a new technology. For producers, welfare may either increase or decrease due to a technological innovation. In most instances, innovation may reduce production costs, increase productivity, or increase the quality of outputs. When a technology reduces production costs and/or increases supply of a good, producers will benefit if the value of the increased quantity sold outweighs the effect of any price reductions (demand is relatively elastic). Alternatively, producers will be negatively impacted if the price decrease effects dominate changes in quantity demanded (demand is inelastic). Consumers in both importing and exporting countries can gain from both the reduced prices and any output quality improvements.

The methodology adopted for this analysis generally follows that described by Alston et al. (1995). Adopting an improved storage technology will decrease storage losses and thus increase the grain supply; this will result in a downward/outward shift of the cowpea supply function. As the market for cowpeas is competitive in the countries examined, this increased supply will lead to a reduction in cowpea market prices. Because cowpea is an export crop, its demand is relatively elastic; as such, both producers and consumers can benefit from the CRSP storage innovations.

When combined, these net benefits can be used to assess the impact of the CRSP investment in cowpea storage technologies. To reflect the benefit due specifically to the post-harvest technology, this standard approach was supplemented by a two-period storage model developed by Fuglie (1995). In this model, production takes place in only one period but farmers have the option of selling their output at harvest (Period 1), or storing all or part of their crop in the hope of gaining better prices at a later time (Period 2). To discount returns from storage between period 1 and period 2, the opportunity cost of capital for agriculture in West Africa is used in the Fuglie model. For each period, the Fuglie (1995) model allows estimation of both consumer and producer surplus for each year of the technology adoption period. The analytic solutions provided by Fuglie (1995) estimate changes in producer and consumer surplus due to storage as a function of several parameters including: the discount rate, change in storage costs, change in storage losses and the original price and quantity levels before new storage technology was introduced. Summary financial statistics are then used to aggregate the flow of benefits and costs over time. In this analysis, two financial measures will be used: the internal rate of return (IRR) which is the discount rate at which the present value of the costs equals the present value of benefits (Barry et al., 2000), and the net present value (NPV) which is the amount by which total benefits exceed total costs (Barry et al., 2000). The following discussion describes the data requirements and parameter estimation procedures used in this analysis. A more detailed description of the methods and assumptions employed in this study is presented in Moussa (2006).

2.1. Data

Data needed to calculate the social benefit of a technological innovation include market prices and quantities, supply changes induced by the new technology, technology adoption costs, and economic parameters such as the elasticities of supply and demand of relevant products (Masters et al., 1996). Information regarding CRSP research and extension costs is also needed.

To the extent possible, data and parameters used in this analysis were based on information collected directly from cowpea producers and consumers. When necessary, information was obtained from CRSP partner organizations, and national and international data sources. The following discussion highlights the primary and secondary data collection process.

2.1.1. Primary data

Information regarding cowpea production and usage, cowpea storage techniques, the proportion of cowpea production which was stored, costs associated with storage technology adoption and use, and socio-economic characteristics of cowpea producers was collected through village and household level surveys in each of the countries included in this analysis. In Benin, Mali and Senegal data were collected in 2004 for the 2003 production cycle. For Burkina Faso, Cameroon, Niger and Nigeria, the data regarding 2004 production were collected in 2005. In each country, ten villages located in major cowpea growing areas were randomly selected based on a list of villages and/or a map. Within each village, farmers were randomly selected from an exhaustive list of the farming households which was drawn up during a village meeting. Including the head of the village (who is always interviewed in accordance with the local custom) and some women who were selected separately, 11 to 15 farmers were interviewed in each village. Thus, in total, 795 farmers were interviewed. Among these, 120 were farmers from Benin, 116 from Burkina Faso, 112 from Cameroon, 149 from Mali, and 108, 104, 86 from Niger, Nigeria, and Senegal respectively. Approximately 6% of the respondents were women who were heads of households. Among those surveyed, 41% of farmers lived in sites which had received specific extension or NGO training in cowpea storage, while the remainder had not previously received storage training. This access to the extension or NGO training program was the only benefit the farmers enjoyed; there were no grants directly to farmers.

2.1.2. Secondary data

While village and household surveys provided most of the data used in this analysis, some information was not available through this source. Price data across time were obtained from several sources including agricultural extension services, Bean/Cowpea CRSP survey data, and data from other institutions. In Niger, for example, data were obtained from SIMA (Système d'Information sur les Marchés Agricoles). This project has been collecting price data since 1989 for major agricultural products from approximately fifty markets located throughout the country. For Burkina Faso, market prices were obtained through regional statistical services of the Ministry of Agriculture. Price data for Cameroon were obtained from annual reports of the Ministry of Agriculture for the Far North province (1986–1991; 2003–2005) and also agricultural statistical yearbooks (1999, 2000, and 2002). For Nigeria, prices were obtained from Musa Shehu of Bayero University of Kano (Musa, 2003). Prices previously collected through the Bean/Cowpea CRSP were used for Mali (Jamal, 2005), and Benin data was obtained from IITA. Cowpea production quantities were obtained from agricultural extension services and FAO statistics (FAO, 2005).

2.2. Parameter estimation

Individual and village-level survey results were used to estimate most of the parameters used in the economic impact analysis. The following section details the approach used to estimate key parameters required for the impact assessment.

2.2.1. Adoption of improved storage technology

Critical to this analysis is the estimated rate of adoption of the improved storage technology. A lag exists between the successful development of a new technology and its adoption by users. In considering the pattern of technology extension and its adoption by users, agricultural technologies are often well represented by a logistic S-shaped curve (Griliches, 1958). This functional form implies that technology adoption begins slowly, enters a phase of steep adoption, and finally reaches a maximum 'plateau' level of adoption by farmers. This analysis assumes that the adoption of CRSP storage technologies in West and Central Africa can be characterized by this pattern. The level of adoption in a particular period is estimated using the following formula of the logistic growth curve:

$$A_t = M/(1 + b^* \exp(-t)) \quad (1)$$

Where:

A_t = the level of adoption in year *t*

M = the plateau adoption level

b = the adoption rate coefficient

The plateau adoption level (M) and the adoption rate coefficient (b) are the two key parameters that need to be determined. There is, unfortunately, no standard approach to elicit the values of these parameters. Alston et al. (1995), for example, suggested that one could base the judgments on points on the curve that are easier to guess. A reasonable judgment, that is usually made, is to assume a very low adoption in the year of release, for example $A_0 = 0.01$ to estimate one point on the curve. The scientists and extension workers could also be asked to estimate the likely adoption rate after the technology release in a particular year or to give a best estimate of the number of years required after the release of the technology before reaching 50% of the plateau level, for example $A_{10} = 0.5$ M.

In the case of this research, estimates of the parameters can be obtained from the data. Improved storage technologies, especially metal drum storage, and double and triple bagging techniques, are most likely to be adopted in areas where relatively large quantities of cowpea are produced per farmer. This is due both to the fact that the per-unit storage costs decline with the volume stored, and that, to be most effective, many of the improved technologies require that a minimum quantity of grain is stored. For example, due to the need for hermetic conditions, metal drum storage is effective only when the drum is completely filled.

It is quite difficult to determine the plateau level of technology adoption. For most nations included in this analysis, it is unlikely that the adoption of CRSP technologies has plateaued. The exception to this is in Senegal where the improved storage technology was introduced much earlier, and research indicates that adoption of the CRSP drum technology adoption may be decreasing (Boys et al., 2007). Two approaches can be used to estimate the plateau level of adoption: estimation from the adoption lag length or estimation from the maximum adoption achieved by subgroups (e.g. villages with specific storage training). The adoption lag length, which is the period between the release of the technology and its maximum adoption by farmers, varied with the case studied. Alston et al. (1995) assumed the adoption lag to be six years, while Lowenberg-DeBoer and Faye (1996), and Diaz-Hermelo and Lowenberg-DeBoer (1999) assumed lags of 10 and 7 years respectively. Because adoption lag estimates varied across sites and sources, this analysis instead opts to estimate the adoption plateau on the basis of the maximum adoption achieved by sample subgroups.

To estimate the adoption rate coefficient (parameter b in Eq. (1)), in addition to the plateau level, estimates of technology adoption in at least one period (parameter A), is required. Using estimates of cowpea stored with each storage technology, the adoption rate in 2004 (2003 for Benin, Mali, and Senegal) is calculated using the following formula noted in Eq. (2). It is important to note that Eq. (2) is the formula to calculate the weighted average use of the improved technology to store cowpea at the farm level, a statistic that will then be used to estimate the adoption rate in each year in the different countries.

$$A_A = \text{\% of cowpea produced in the main production area} * (W_{TV} * A_{TV} + W_{NV} * A_{NT}) \quad (2)$$

Where:

A_A = adoption in the survey year,

W_{TV} = percentage of trained villages relative to the total number of villages in the main cowpea area,

A_{TV} = technology adoption in trained villages as a percentage of total cowpea production in those villages,

W_{NV} = percentage of non-trained villages relative to the total number of villages in the main cowpea area,

A_{NT} = technology adoption in non-trained villages as a percentage of total cowpea production in those villages.

2.2.2. Demand and supply elasticities

There are no studies, to our knowledge, available which empirically estimate cowpea supply and demand elasticities in West Africa. Although it would be possible to estimate these elasticities with a small amount of data the reliability of the estimates would be questionable. Thus, the challenge here is the availability of good data to estimate these elasticities. In this study we have chosen to use elasticity measures from related studies. Typically supply elasticities fall within the range of 0.2–1.2 while elasticities of demand are between −0.4 and −10 (Masters et al., 1996). Langyintuo (2003) reported supply and demand elasticities for some agricultural products that fell into the lower end of these ranges. Large elasticities of demand occur when a commodity is traded openly in larger international markets; lower demand elasticities reflect instances where food products trade is limited to local markets. In almost all countries cowpea trade is open to international markets, but this trade occurs mainly between countries in West and Central Africa.

Langyintuo et al. (2003) report that cowpea trade is clustered around Senegal and Nigeria. For the purpose of this analysis, demand in each country is assumed to be the sum of local consumption and export demand. Cowpea purchased for export is treated as consumed and cowpea stored for local consumption is taken into account by the storage model. As most cowpea is traded during the harvest period this period is assumed to face a relatively high elasticity of demand; based on the range reported in Masters et al. (1996), an elasticity of 5 was selected for the baseline, in the Fuglie model. The remaining cowpea is stored to be sold later during the year when the reduced supply of grain results in higher market prices (Period 2; April to September). It is assumed that during this period, cowpea grain demand is characterized by a relatively low elasticity of demand. Lower elasticity estimates reported by Langyintuo (2003) are used to characterize cowpea demand in Period 2, and cowpea supply. Robustness of baseline results to these elasticity assumptions was evaluated through sensitivity testing.

2.2.3. Cowpea storage losses

The improved storage technology reduces the loss of cowpea grain to pests and, in doing so, effectively increases cowpea supply. To estimate the impact of these technologies on cowpea supply two parameters are needed: (1) the proportion of grain lost when stored under traditional technologies, and (2) the proportion of grain lost when stored under an improved CRSP technology. Grain loss during storage by traditional methods was estimated using the average of grain lost weighted by the distribution of the various storage technologies used at the time the improved storage technology was disseminated. This information is only available in the case of Cameroon from Wolfson et al. (1991). Based on these estimates, Diaz-Hermelo and Lowenberg-DeBoer (1999) found that the weighted average loss of 52% is a reasonable estimate for traditional methods. In the current surveys, most farmers reported that without treatment or just using botanicals, 100% of the stock may be lost in a few months. For Senegal Lowenberg-DeBoer and Faye (1996) used an estimate of 25% loss. This conservative 25% loss rate is used in the baseline analysis and the impact of the higher rate of 50% is evaluated through sensitivity testing.

For the improved CRSP storage technologies most farmer respondents stated that when the techniques are properly used no loss was observed. Based on surveys in Senegal, Boys et al. (2007) estimated cowpea loss under drum storage to be 0.6%. In instances where no other reliable information is available, this rate is used. Loss rates of 1% are evaluated through sensitivity testing.

2.2.4. Storage costs

Several cowpea storage methods which were commonly used prior to the dissemination of the CRSP improved storage technologies continue to be used. In most countries simple woven bags, clay pots (canary, jar), jugs ('bidon' in French) and even calabashes are used to store relatively small quantities of cowpea grain. To estimate the cost of these traditional technologies, estimates of storage costs from this survey and previous studies are used in the analysis.

2.2.5. Producer opportunity cost of capital

The opportunity cost of capital is defined as the expected return that is foregone by investing in a project rather than in comparable financial securities (Gittinger, 1982; Lee et al., 1980). While the returns on a variety of financial instruments can be used as a measure of the opportunity cost in developed countries (e.g. US treasury bonds), alternative approaches must be used in developing country cases where financial markets are imperfect or incomplete. Most previous technology assessment studies used rates of return on capital for agriculture in West Africa in the range 0%–300%. More recently, Lowenberg DeBoer et al. (1994) found that some farmers in the Sahel region of West Africa have a cost of capital even above this range but it varied widely. Among the various categories of small business evaluated by the different studies, livestock activities could be compared to the farm storage activity considered in this study. Estimated livestock rates of return reported by Lowenberg DeBoer et al. ranged from 40% to more than 100%. For the baseline analysis, the annual rate of 100% that falls both in the previous range and the range found for livestock investment is used. Thus, since the storage period covers six months, the discount rate of 50% is used in the Fuglie model. The approximate opportunity costs of capital in developed and developing countries of 10% and 50% respectively is assessed through sensitivity testing.

2.2.6. Proportion of cowpea consumed in period 1

Previous studies do not provide any insight concerning the proportion of grain which is consumed versus that which is stored following harvest (Period 1). In all of the countries studied, however, it is known that a large part of cowpea production is either consumed or sold at harvest. In their case study of Senegal, Lowenberg-DeBoer and Faye (1996) assumed 70% of cowpea production was consumed in period 1. Also, Diaz-Hermelo and Lowenberg-DeBoer (1999) assumed 80% first period use in their baseline analysis. Following these studies this analysis assumes that, for all countries, 70% of cowpea production is consumed during period 1 and that the remaining 30% is stored for second period use. This assumption is evaluated through sensitivity testing where the impact of a lower rate of first period consumption (higher storage rate) of 50% is assessed.

2.2.7. Price and quantity projections

A successful research investment generally yields a sustained stream of future benefits (Alston et al., 1995). An economic impact assessment must therefore take into account the dynamic relationship between investments and future benefits. Alston et al. (1995) estimated that the adoption process can occur over a span of up to 20 years. Based on this, future benefits of this technology are projected up to 2020. Future levels of cowpea grain production, and prices for each of the two periods, are taken as the simple average over the last five years.

2.2.8. Research and extension costs

Research costs were incurred only in Cameroon and Senegal. Good estimates of extension costs are not available for Senegal. For Cameroon, research and extension costs were estimated by Diaz-Hermelo and Lowenberg-DeBoer (1999). For the period 1988 to 2002, these authors estimated that the total expenditure on cowpea storage research was $1,941,853 in 1998 U.S. dollars (USD). The extension expenditures for the period 1992 to 2005 were estimated to be $313,515 in 1998 USD. Extension efforts funded by this expenditure included both the extension of storage technologies and new cowpea varieties. As there is no practical way to allocate extension expenditure between these efforts, and as storage technology dissemination was the primary focus of this extension program, this analysis assumes that all extension costs are attributable to the storage technology.

In addition to CRSP-funded extension programs, many other organizations have contributed to the dissemination of the improved storage technologies. In most instances, organizations which contributed to technologies dissemination did not have programs dedicated solely to these technologies. Except for World Vision which had a specific training program on CRSP storage techniques, government extension programs and PRONAF's cowpea program would have existed with or without the CRSP innovations.

Therefore, to estimate the cost for (specifically) extending storage technologies, for countries other than Cameroon, estimates were based on that nation's data. An extension cost of $200 USD per village was estimated and used for the analysis. It is important to note that the farmers were not direct recipients of any grants from USAID, any of the national governments or any of the NGOs. The farmers received information when they participated in training programs. The funds from these agencies contributed to the research and extension programs that developed and disseminated the knowledge of how the storage technology could be effective. Measuring the return to this investment is the objective of this research.

2.2.9. Inflation adjustments

To account for inflation, prices and costs were adjusted from nominal to real values using the relevant CPI index for each country. These data are available through IFS statistics (IFS, 2005). Also, in the calculation of economic surplus, all benefits and costs were expressed in USD and adjusted using the US GNP deflator. This index was selected due to the fact that the US government was the principal donor for this project. Exchanges rates used to convert national currency to USD were also obtained from IFS statistics (IFS, 2005).

3. Results and discussion

3.1. Adoption of improved storage technology

For each country included in this analysis, the adoption rate in the initial survey year, and the maximum adoption level (plateau level) were estimated for each technology. The outcomes of these calculations are discussed below:

3.1.1. Estimation of the maximum adoption level

The study sample included two types of villages – those which did and did not receive cowpea storage training. Results find that, in most of the studied countries, there was a significantly higher level of technology adoption in villages which had received specific training than those which did not. The quality of provided information and logistic support contributed to the better adoption in these training villages. In some cases, however, good information was also reported as being available in non-training village through others sources such as general extension services. This was especially the case for technologies which have been available for a relatively long period of time such as the closed-top metal drum. For other reasons as well, the storage training which a village received was not felt to be a useful analytical distinction. In most examined countries, information was not available concerning which villages received storage-specific training. Importantly also, among storage-specific training programs, the attention paid to the different technology options varied considerably. Many NGO storage programs outside of Senegal, for example, did not include the metal drum technology because it was deemed to be too expensive for farmers. As the level of storage training a community received could not be used to guide estimates of potential technology use and plateau levels, this analysis conservatively assumes that the highest adoption level observed in each country is the plateau level of adoption.

Table 1 presents the plateau level parameter (M) calculated for each country as the percentage of total production stored under each of the improved technologies.

It is worth noting that in some countries like Mali and Niger, survey results indicate that adoption rates are relatively low. Although previous studies have found that adoption of storage technologies are in general low (Coulter and Mcgrath, 1994), in this case the result could be explained by the data. Given that results are higher in other neighboring nations, it was assumed that these estimates are probably a good indication of the potential plateau level. Taking into account the importance of cowpea production in these countries and the fact that adoption is continuing in these areas, it was assumed that the plateau adoption level would at least reach that observed in neighboring countries like Burkina Faso or Nigeria.

The weighted average national technology adoption levels in 2004 (2003 for Benin and Mali) are estimated and presented in Table 2. The highest adoption rate in 2004 was found in Senegal where the metal drum technology was used to protect about 48% of cowpea grain which was stored. Nigeria had the second-highest adoption level; here the double-bagging technology was used to house about 23% of stored production. In two cases an adoption rate of less than 1% was registered; the double-bagging technology in Mali and the metal drum technique in Niger were each used to protect about 0.2% of stored production.

3.1.2. Insecticide

Farmers storing grain using traditional technologies frequently add insecticide (e.g. Phostoxin or Actellic powder) to reduce grain loss due to infestation. This study found considerable inter-country variation in the use of these chemicals. Among those using traditional storage techniques, the percentage of farmers who also used insecticide during cowpea storage varied from 16% in Burkina Faso to 38% in Nigeria. Twenty-two percent of farmers in both Niger and Cameroon also reported using insecticide.

Grain stored using the CRSP improved technologies does not require the use of insecticide; through a variety of mechanisms, each of the CRSP-improved storage technologies both effectively control insects trapped with the grain during storage and provide a barrier to further infestation. Despite this, however, in all of the countries studied it was found that insecticide is still widely used as 'anti-infestation insurance' even among farmers who had also adopted the improved technologies. This is particularly true among producers who adopted double bagging rather than the recommended triple bagging technique. For the metal drum technique most farmers are aware that when the drum is filled up, there is no

Table 1
Estimation of adoption plateau level.

	M = Plateau Level[a]		
	Ash	Double/Triple-Bagging	Metal Drum
Benin	0	0	0.256
Burkina Faso	0.244	0.277	0.321
Cameroon	0.135	0.306	0
Mali	0.244	0.277	0.321
Niger	0	0.286	0.188
Nigeria	0	0.286	0.188
Senegal	0	0	0.479

[a] Calculated as proportion of cowpea production in the main area multiplied by the proportion of the production stored within the technology.

Table 2
Estimation of adoption of improved technologies in 2003 and 2004.

	Proportion of Cowpea Production Stored		
	Improved Ash	Double/triple-bagging	Metal Drum
Benin	0.000	0.000	0.127
Burkina Faso	0.134	0.127	0.075
Cameroon	0.099	0.089	0.000
Mali	0.050	0.001	0.073
Niger	0.000	0.033	0.002
Nigeria	0.000	0.229	0.150
Senegal	0.000	0.164	0.479

need to add insecticide. In instances where the drum is not completely filled, however, some farmers reported using an insecticide.

The percentage of the production stored on farms using storage insecticide demonstrates how widely these chemicals are still used. Nigeria has the highest average (weighted) percentage of the production stored using insecticide with 67.7% followed by Burkina Faso with 34.9%. In Cameroon and Niger these percentages are 34.9% and 10.5% respectively. The types of storage insecticides purchased by farmers are quite variable. These products were rarely identifiable by their users because they are largely purchased from unregulated merchants in local markets rather than through formal sector sources. Also troubling, are reports that these merchants sell unapproved insecticides for cowpea storage purposes.

3.2. Storage costs

The annual cost of using improved storage technology is estimated based on data reported in the different countries. Table 3 presents the per kg cost of cowpea storage using each of the improved technologies. The improved ash method recommends mixing cowpea grain with ash in equal proportions prior to storage. The baseline cost of this technique varied as a function of clay pot prices (reported purchase price was between 1500 and 1800 FCFA) and the cost of labor. Cost for the double-bagging technique was estimated based on the cost of the interior plastic bag and exterior woven sac. Due to use of the plastic bag, the cost of this improved technology is higher than for the traditional bagging technique. It is important to note that the plastic bags were produced locally in Africa and were produced for purposes other than the storage of cowpea. Farmers bought them in their local markets at the market price.

The annualized cost of storage using the metal drum technology was calculated based on the minimum and maximum drum purchase price and labor costs reported in the surveyed countries. The maximum average purchase cost for a closed-top drum is found in Burkina Faso and the minimum in Niger. This is higher than the cost of open-top drums which were assumed to be one half of the cost of closed-top drums. Additional labor is required to use the closed as compared to the open-top drum due to the time it takes to fill a closed container through the drum bunghole with a funnel. The maximum labor cost for filling the drum is found in Benin and the minimum in Niger. Despite the additional cost for labor required for storage under the improved drum technology, the cost of using the traditional drum technology was found to be slightly higher.

3.3. Solar heating

In most of the studied countries, the solar heater technique was rarely used by individual farmers to treat their cowpea grain. In Cameroon and Burkina Faso, however, some farm organizations that specialize in seed production use solar heaters. The quality requirement of the seed appears to be the main factor which motivates use of this technique. In Burkina Faso, farmers in the village of Zikieme were trained in cowpea seed production and were required to use the solar heater prior to storage using plastic bags or metal drums to help maintain seed quality. In this case, as in the previous example, farmers did not independently own their own solar heater. Although the reason given by some farmers for not purchasing their own unit was that they could not afford to buy it, given that farmers frequently already possessed the required black plastic, acquiring the needed clear plastic sheet appeared to be a constraint. As noted by some farmers, clear plastic is difficult to find and is rarely available in market places even in large cities.

Other farmers argue that the traditional method of drying grain in the sunlight is very effective and are not convinced of the need or benefit of using solar heaters. Discussions with extension agents in Cameroon revealed that one of the problems with solar heater adoption is a lack of information. Many farmers did not understand the principle of the solar heater technique, or the difference between traditional drying and the improved drying technique. In addition, some farmers pointed out that it takes too much time and labor to treat a large quantity of cowpea with the solar heater.

Table 3
Range of annual cost of storage with alternative technologies.

Technology	Cost (FCFA/kg)		Cost(USD/metric tonnes)	
	Minimum	Maximum	Minimum	Maximum
Traditional				
Clay Pot	9.6	11.0	13.8	15.8
Woven bag	5.1	6.9	7.3	10
Open drum	9.9	13.5	14.2	19.4
Improved				
Improved Ash	11.9	13.6	17.1	19.5
Double/Triple bag	11.4	16.7	16.4	24
Metal drum	9.5	13.1	13.6	18.8

3.4. Impact assessment results

Total net benefits were estimated using the standard surplus economic approach supplemented by the Fuglie (1995) model. The stream of benefits were first estimated by country and then aggregated to the regional level. The financial measures of Internal Rate of Return (IRR) and the Net Present Value (NPV) were used to assess the economic impact of CRSP investment in storage technologies in West and Central Africa. The NPV is the net present value of a project, i.e., the present value of benefits minus the present value of costs while the IRR is the discount rate that would result in a zero value for the NPV of a project (Alston et al., 1995). Results from the baseline analysis are discussed next; sensitivity tests outcomes are then presented and evaluated.

3.4.1. Baseline results

Results presented in Table 4 indicate that, at the regional level, this project is estimated to have an NPV of $295,369,390 year 2000 USD and the IRR was estimated to be 28.6%. At a national level, results indicate that the highest absolute returns were generated in Nigeria where the net benefits were estimated to be $198,917,911 in 2000 USD and IRR to be 53.7%. Following Nigeria, Burkina Faso and

Table 4
Economic surplus results – baseline estimates including research and extension costs.

Country	Financial Measure	
	Internal Rate of Return (%)	Net Present Value (Year 2000 USD)
Benin	94.9	4424513
Burkina Faso	132.3	38533124
Cameroon[a]	8.3	1470139
Mali	88.4	15201388
Niger	54.4	27764733
Nigeria	53.7	198917911
Senegal[a]	16.9	9057581
Regional	28.6	295369390

[a] Cameroon and Senegal are the countries where research costs were incurred and thus the net returns are lowest. For Cameroon research and extension costs were estimated to about 2 million and more than 300,000 in 1998 US dollars, respectively.

Table 5
Present value (PV) analysis by technology and by country.

Country	Ash Method PV (USD)	Double-Triple Bag PV (USD)	Metal Drum PV (USD)
Benin	0	0	4504517
Burkina Faso	10979821	12905947	14807322
Cameroon	1047885	2067893	0
Mali	4757495	3611152	6992708
Niger	0	18504410	9660247
Nigeria	0	123550645	86944510
Senegal	0	1795095	9964563
Regional	16785201	162435143	132873866

Niger experienced the next highest levels of benefit; storage investment returned NPV estimates of $38,533,124 USD (IRR = 132.3%) and $27,764,733 USD (IRR = 54.4%) respectively. The IRR is used here for most cross country comparisons because it is insensitive to the size of the cowpea market in the country; it is determined by the relative benefits and costs over time. Given the relative production levels in the surveyed countries, it was expected that Nigeria would experience the greatest benefit from this program. Production levels do not, however, explain the position of Burkina Faso as compared to Niger. Instead, the relatively high storage technology adoption rates in Burkina Faso led to notable NPV in spite of that nation's modest production. In this vein, it is interesting to note that the improved ash storage method was not adopted at all in either Nigeria or Niger, but that Burkina Faso reported a relatively high adoption rate of even this technology.

The lowest investment returns were generated in the countries in which the storage research was conducted. An IRR of 16.9% was generated in Senegal and an 8.3% IRR was estimated for Cameroon. Given the cost of research this outcome is not surprising. The lower returns for Cameroon are due, in part, to extension expenditure. Due to the lack of a basis for disaggregating extension costs between cowpea projects, this expense was fully attributed to the storage program but in practice it also supported the extension of improved cowpea varieties. In the case of Senegal the extension costs were unknown and were therefore estimated for three years using the generalized approach outlined in the methodology section.

The IRR generated through this project was compared to the cost of capital of West African governments and the formal private sector in order to evaluate the profitability of the research investment. Among West African countries, the government of Ghana sells bonds; after adjusting for inflation, the interest rate on these bonds was estimated to be 8.9% and 5.4% in 2004 and 2005 respectively. Using these rates as a reference for other West African government capital returns, the CRSP storage program was a very good investment. For the private sector, bank lending rates can be used as a measure of the nominal cost of capital. For Cameroon and Nigeria over the project period from 1996 to 2005 these rates were an average of 20.2% and 20.3% respectively (IFS, 2005). Adjusted for inflation the real lending rates were 13.8% and −3.5% for Cameroon and Nigeria respectively and together they averaged to a real rate of return of about 5%. Thus, compared to the cost of capital in these developing nations, this project is a good investment.

It is also useful to compare the IRR with the cost of capital in the US since the US government was the major financer for the project under consideration. A standard measure of the opportunity cost of capital available to the US government is the return available through investment in US Treasury bonds. At the time of this CRSP investment, this rate was 4.8%. Both regionally and within each surveyed nation the rates of return far exceed this level. Thus, even compared to the cost of capital in the US, the principal donor, the project remains a good investment.

With regard to specific technologies, results indicate that the double and triple bagging technology generates the highest regional benefit; the PV for this technology was estimated to be $162,435,143 USD (Table 5). The metal drum technology generated the second-highest level of benefit; returns to investment in this technology were estimated to be $132,873,866 USD. At the country level, returns for the use of double bagging were concentrated in Nigeria, but were notable in Niger and Burkina Faso. Nigeria also captured the bulk of returns from the use of the metal drum storage technique. Burkina Faso, Senegal and Niger, however, also experienced substantial benefit from this technique. Benefits of the improved ash method were primarily concentrated in Burkina Faso and Mali.

3.4.2. *Sensitivity analysis*

Sensitivity analysis was used to assess the impact of assumptions concerning the model parameters on the baseline outcomes. In particular, changes in the following were considered in the sensitivity analysis: demand and supply elasticities, percentage of storage loss, opportunity cost of capital, proportion of grain stored, the storage method actually evaluated (to consider only the use of

Table 6
Results from baseline and sensitivity tests.

Measure	Baseline Parameter Value	Sensitivity Test Parameter Value	IRR (%)	NPV(2000 USD)
Baseline			28.6	295369390
Sensitivity on Elasticity			28.9	294740744
Demand Period 1	5	10		
Demand Period 2	0.2–0.5	0.2–0.5		
Supply	0.08–0.24	0.2–0.5		
Sensitivity on Storage Loss				
a. Old technology loss rate	25%	50%	35.7	675911354
b. New Technology loss rate	06%	1%	28.5	291212547
Sensitivity on Opportunity Cost of Capital				
a. Baseline	100%			
b. Opportunity cost of capital in developing countries		50%	23.3	152,046,890
c. Opportunity cost of capital in developed countries		10%	25.3	195,559,257
Sensitivity on Proportion of grain stored	70%	50%	32.9	509753845
Storage without insecticide use		Adoption of Pure CRSP Technology Only[a]	25.2	243540210
Hermetic Storage only		Adoption of only Hermetic Improved Storage Methods[b]	28.3	278650491

[a] Farmers still use insecticide with improved technologies which are originally non-chemical. The Baseline includes adoption of all improved technologies. In this case net benefits were estimated based on only the pure improved technology, that is the insecticide use is excluded.
[b] For this alternative only adoption of hermetic improved storage (triple bagging and drum) is taken into account. The ash method is excluded because in some cases it was difficult to distinguish between the traditional and improved methods.

the CRSP technology) and the use of only hermetic storage. Overall these tests indicate that the baseline results are relatively robust (Table 6). The projected IRR decreased in some of the cases involving sensitivity analysis: these were, when the storage loss for the new technology increased to 1%, when the opportunity cost of capital in developing countries was decreased to 50% and 10% and when only adoption of CRSP technologies and hermetic improved storages were considered. These results suggest that the baseline analysis offers a conservative estimate of the potential economic impact of this project.

As would be anticipated, the impact of changes in particular parameter values did vary. Moderate changes in assumed levels of supply and demand elasticities had an insignificant effect on the overall estimate of social gain. In contrast, the model proved to be relatively sensitive to changes in parameters which characterize the extent of grain lost during storage using 'old' (traditional) techniques, the proportion of cowpea stored in Period 1, and the opportunity cost of capital. This result suggests that future, similar analyses would do well to be particularly careful in estimating these parameters.

4. Conclusions

The development and dissemination of improved technologies to store cowpea grain has been a major initiative of the Bean/Cowpea CRSP, NGOs, and the extension services of several African nations. It was the purpose of this analysis to measure the economic impact of the non-chemical CRSP cowpea storage technologies in West and Central Africa. Of particular interest was the impact of CRSP improved ash storage, double or triple bagging and closed-top metal drum storage techniques.

To obtain estimates of storage technology adoption and effectiveness, a random sample of farmers were surveyed in the main cowpea growing areas of Benin, Burkina Faso, Cameroon, Mali, Niger, Nigeria and Senegal. In spite of the fact that the research activity was only in Senegal and Cameroon and the extension activities were limited, this study found evidence of the wide dissemination and use of hermetic storage techniques. Over 20% of farmers in Burkina Faso, Cameroon, Mali and Nigeria reported using the double and triple bagging method. In countries where 200 L metal drums were relatively inexpensive, many farmers reported also using them for cowpea grain storage. In Senegal, where the drum storage technique was developed, 69% of households in the main cowpea growing area use this technique. Drums are also widely used in Nigeria, Burkina Faso and Benin. Plastic jugs and other sealable plastic and metal containers were also reported as being used to store smaller quantities of cowpea grain. Overall it is estimated that approximately 30% of grain in the region is stored using the CRSP-developed double and triple bag or closed metal drum storage techniques.

Though storage insecticides are not needed with hermetic storage technologies, many farmers reported using insecticides as additional 'insurance' against infestation. This was especially true when grain was stored using the double or triple bag techniques. While an improved ash storage method was also disseminated, its adoption is concentrated in Burkina Faso, Mali and Cameroon, and it is reported to be used to store only a small quantity of grain ($\sim$1% of regional production). A fourth technology, a solar heater, was also disseminated but was found to be used in only a few villages in Cameroon and Burkina Faso which have been the recipients of extensive cowpea extension programs. It is important to note that the extension programs were solely educational in nature and did not involve any direct grants to the farmers.

From both the perspective of African countries and of the principal project donor, the US government, this project was shown to be a good investment at the regional level and independently within each country that received research and/or extension support. The internal rate of return was found to be substantially greater than the cost of capital for the recipients' countries and the principal donor for all the countries where CRSP's storage technologies are being currently used by the farmers. Country level returns were estimated to be highest for Burkina Faso, Benin and Mali which respectively experienced storage returns of 132%, 95%, and 88%. In the remaining surveyed countries, the IRR varied from about 54% in Niger to 8% in Cameroon. At the regional level, the IRR was estimated to be 28.6%, and the net benefit generated across the period of this cowpea program (1982-2020) was estimated to be more than $295 million USD. These results proved to be generally robust under sensitivity testing.

Acknowledgments

This publication was made possible through support provided by the US Agency for International Development under the terms of Grant No. CR-9084-425215 and the USAID Bean/Cowpea Grant No GDG-G-00-02-00012-00. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S Agency for International Development, or the Bean/Cowpea CRSP.

References

Alston, J., Norton, G., Pardey, P., 1995. Science under Scarcity. Cornell University Press, Ithaca, New York.
Barry, P.J., Ellinger, P.N., Hopkin, J.A., Baker, C.B., 2000. Financial Management in Agriculture. Interstate Publishers Inc., Danville, IL, USA.
Boys, K., Faye, M., Fulton, J., Lowenberg-DeBoer, J., 2007. The impact of cowpea research in Senegal: an ex-post analysis with disadoption. Agricultural Economics 36, 363–375.
Coulter, J.P., Mcgrath, P., 1994. Economics of grain handling and storage in developing countries. In: Grain Storage Techniques: Evolution and Trends in Developing Countries. FAO Agricultural Services Bulletin 109, 1–24.
Diaz-Hermelo, F., Lowenberg-DeBoer, J., 1999. Estimating Research Benefits with both Production and Post-Harvest Technology: The Case of Cowpeas in Cameroon. Bean/Cowpea CRSP West Africa Regional Report #2.
FAOStat, 2005. FAO Statistical Databases [Online] Available at. http://apps.fao.org.
Faye, M., Lowenberg-DeBoer, J., 1999. Adoption of Cowpea Improved Varieties and Storage Technologies in the North Central Peanut Basin of Senegal and Economic Impact Implications. Bean/Cowpea CRSP West Africa Regional Report #3.
Fuglie, K., 1995. Measuring welfare benefits from improvements in storage technology with application to Tunisian potatoes. American Journal of Agricultural Economics 77, 162–173.
Gittinger, J., 1982. Price, Economic Analysis of Agricultural Project. Johns Hopkins University Press, Baltimore, MD, USA.
Griliches, Z., 1958. Research costs and social returns: hybrid corn and related innovations. Journal of Political Economy 66, 419–431.
International Financial Statistics (IFS), 2005. [Online] International Monetary Fund. Available at. http://ifs.apdi/net.
Jamal, M.R., 2005. Consumer Preferences for Cowpea Characteristics in Mali. M.S. Thesis, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
Langyintuo, A.S., 2003. Cowpea Trade in West and Central Africa: A Spatial and Temporal Analysis, PhD Dissertation, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
Langyintuo, A.S., Lowenberg-DeBoer, J., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Kushwaha, S., Musa, S., Ntoukam, G., 2003. Cowpea supply and demand in West and Central Africa. Fields Crops Research 82, 215–231.
Lee, Warren, Boehlje, M.D., Nelson, A., Murray, W., 1980. Agricultural Finance, seventh ed. Iowa State University Press, Ames, Iowa, USA.
Lowenberg-DeBoer, J., Faye, M., 1996. Adoption of Cowpea Improved Varieties and Storage Technologies in the North Central Peanut Basin of Senegal and Economic Impact Implications. Bean/ Cowpea CRSP West African Social Science Working Group Report # 3.
Lowenberg-DeBoer, J., Abdoulaye, T., Kabore, D., 1994. The Opportunity Cost of Capital for Agriculture in the Sahel: Case Study Evidence from Niger and Burkina Faso. Staff Paper. Department of Agricultural Economics, Purdue University, West Lafayette Indiana.
Masters, W.A., Coulibaly, B., Sanogo, D., Sidibe, M., Williams, A., 1996. The Economic Impact of Agricultural Research: A Practical Guide. Purdue University West Lafayette, Indiana.

Moussa, B., 2006. Economic Impact Assessment of Cowpea Storage Technologies in West and Central Africa M.S. Thesis, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
Murdock, L.L., Shade, R.E., 1991. Eradication of cowpea weevil (Coleoptera: Bruchidae) in cowpeas by solar heating. American Entomologist 37, 228–231.
Murdock, L.L., Seck, R.E., Ntoukam, G., Kitch, L., Shade, R.E., 2003. Preservation of cowpea grain in sub-Saharan Africa - Bean/Cowpea CRSP contributions. Field Crops Research 82, 169–178.
Musa, S.A., 2003. Marketing of Cowpea in Nigeria: Econometric Studies of Quality Factors and Market Integration. Abubakar Tafawa Balewa University, Bauchi, Nigeria.
Schulz, M.A., 1993. Economic Assessment of Cowpea Grain Storage Technologies: A Case Study of Northern Cameroon. M.S. Thesis, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.
Wolfson, J.L., Shade, R.E., Mentzer, P.E., Murdock, L.L., 1991. Efficacy of ash for controlling infestations of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) in stored cowpeas. Journal of Stored Products Research 27, 239–243.