THESIS

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ECONOMIC ASSESSMENT OF COWPEA
GRAIN STORAGE TECHNOLOGIES:
A CASE STUDY OF NORTHERN CAMEROON

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ECONOMIC ASSESSMENT OF COWPEA GRAIN STORAGE TECHNOLOGIES: A CASE STUDY OF NORTH CAMEROON

By

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ABSTRACT

ECONOMIC ASSESSMENT OF COWPEA GRAIN STORAGE TECHNOLOGIES: A CASE STUDY OF NORTHERN CAMEROON

by

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Scientists and policy makers have focused a great deal of attention on reducing post-harvest food loses as part of the overall strategy for coping with possible future food shortages in the developing world. Out of this concern several international and national research institutions have conducted research to quantify the level and causes of on-farm food grain storage losses. Inadequate storage facilities have been blamed for some of the grain losses.

To address this issue, data were collected in northern Cameroon by a Bean/Cowpea CRSP research team. In addition, samples of stored cowpeas were collected from all interviewed households and assessed for storage damage.

Scientists at Purdue University and IRA (under the auspices of the Bean/Cowpea CRSP) developed improved on-farm grain storage technology. The profitability of these technologies was evaluated using benefit-cost analysis to assess their potential attractiveness to different types of farmers--"traditional" and "advanced".

This thesis is dedicated to my parents, John and Valerie Schulz,

and my sisters, Karen, Bonna, Nancy and Debbie.

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KEY TO ACRONYMS

ARR	Average Rate of Return
CFA	African Financial Community franc
CIMMYT	International Maize and Wheat Improvement Center
CRSP	Collaborative Research Support Project
IITA	International Institute of Tropical Agriculture
IRA	*l'Institut de Recherches Agronomiques*
IRR	Internal Rate of Return
MESIRES	*Ministere de l'Enseignement Superieur, de l'Informatique et de la Recherche Scientifique*
MINAGRI	Ministry of Agriculture, Government of Cameroon
MRR	Marginal Rate of Return
NCRE	National Cereals Research and Extension Training Project
NPV	Net Present Value
ROR	Rate of Return
SAFGRAD	Semi-Arid Food Grain Research and Development project
SOCECOTON	*Societe de Developpement du Coton*
TLU	Testing-Liaison Unit
USAID	United States Agency for International Development

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Cowpeas are an important grain legume which is widely grown throughout Sub-Saharan Africa and northern Cameroon. Because many low income households rely on cowpeas as their primary source of vegetable protein, crop improvement research initially focused on increasing crop yields, primarily through introducing new high-yielding varieties. In the mid-1980s, on-farm research showed that grain losses due to storage pests, particularly bruchids (*Callosobruchus maculatus)*, were a major farm level constraint (Singh and Rachie, 1985).

To address this constraint, in 1986 scientists at Purdue University and the *Cameroonian Institut de la Recherche Agronomique* (IRA), under the auspices of the Bean/Cowpea Collaborative Research Support Program (CRSP), initiated research to develop bruchid-resistant varieties and improved post-harvest storage technologies.

During the late-1980s, several alternative cowpea storage technologies were tested, including multiple bagging (plastic) techniques, storage with botanicals (i.e., roots, mint leaves, bark, neem and shea oil, and ash), and various types of containers. In addition, CRSP scientists conducted laboratory and field experiments at Purdue and Maroua, Cameroon to evaluate the feasibility of using solar radiation to kill cowpea bruchids. Initial experiments showed that brief exposure to temperatures of 65 degrees C for 5 minutes will kill 100% of all stages of *C. maculatus*. These results led to the design of a solar heater (made of two plastic sheets and a insulting "mattress" of threshed cowpea pods between the lower black heat-absorbing sheet and the earth), which was tested in research station and on-farm experiments in Maroua, Cameroon.

Results from these trials demonstrated that the solar heater technology effectively eliminated *C. maculatus* infestations, and represented a potentially promising, low-cost technology for extension to farmers.

This thesis analyzes the benefits and costs of the proposed cowpea storage technologies (i.e., improved ash, triple bagging, solar heater with triple bagging) under the socioeconomic situation facing northern Cameroonian farmers.

1.2 Objectives

The general objective of this case study is to assess the feasibility and profitability of proposed storage technologies for cowpeas in northern Cameroon, and to explain the factors that may condition their rate of adoption.

The specific objectives of the study are to:

a. Document the status of cowpeas in Africa including their place in the cropping system and their importance in the diet;

b. Document the levels of storage loss caused by the major cowpea storage insect pests;

c. Describe the traditional and improved storage structures and treatments that farmers and scientists have developed to reduce storage losses;

d. Document the status of cowpeas in northern Cameroon, including how they are grown, utilized, and stored;

e. Review Purdue University/IRA research designed to reduce pest damage, including breeding initiatives and storage technologies;

f. Develop a benefit-cost model, based on farm budgets to estimate financial returns (net benefits) to farmer-adoption of the proposed storage technologies;

g. Conduct sensitivity analysis on the variables included in the benefit-costs model to determine the relative impact of key variables on farmers' net benefits;

h. Provide CRSP researchers with guidelines as to socioeconomic data needs to help plan and evaluate future crop storage projects.

1.3 Hypotheses

This study tests the hypothesis that improved on-farm, low resource storage technologies have high financial and economic returns when measured against the farmers' alternative storage technology. Specifically, it will determine if the net benefit to investment in each of the proposed improved storage technologies are greater than zero. Furthermore, it tests the hypothesis that net benefits are highly sensitive to the cost of materials used to build the improved technologies, (e.g., plastic solar heater and plastic bags), the market price of cowpeas, the volume of grain farmers have to store, the level of loss incurred during the storage period, and the opportunity cost of capital.

1.4 Thesis Organization

The thesis is divided into six chapters. Chapter 2 provides general background about cowpeas in Africa, major storage insect pests, and traditional and improved storage methods. Chapter 3 reviews the status of cowpeas in northern Cameroon, including estimates of storage losses under alternative storage structures and treatments, and describes Purdue University/IRA breeding initiatives and storage technologies developed for low resource farmers. Chapter 4 presents the research design and methodology. Chapter 5 reports estimates of the benefits and costs of the alternative technologies and factors found most critical to determining net benefits. Chapter 6 summarizes the thesis, draws policy implications, discusses the limitations of the study, and identifies future research issues.

CHAPTER 2 COWPEAS IN AFRICA

2.1 Overview of Cowpeas

Africa accounts for an estimated 78% of the world's 8.5 million hectares of harvested area in cowpeas. Of the 6.7 million hectares in Africa, about 61% are in Nigeria, followed by Niger (23%), Burkina Faso (4.6%), Mali (2.5%), Ghana (2.3), Tanzania (1.4%), and Senegal (1.4%) (Bernsten, 1993).

In these countries, cowpeas are grown primarily in the semi-arid regions, where annual rainfall averages 400-1000 mm. In much of the cowpea-growing area, the rainfall coefficients of variations range from 20-40 percent. Because of this extreme variability in year-to-year rainfall, farmers face considerable production risk (Bernsten, 1993).

To assess the relative importance of cowpeas in the food system, Bernsten (1993) calculated the area (harvested) in cowpeas vs. total cereals, roots and tubers, and pulses. Although in most countries cowpeas represent a relatively large share of the pulse area, they represent only a relatively small share of the total harvested crop area.

2.1.1 Cropping System

Cowpeas, the second most important grain legume in Sub-Saharan Africa after groundnuts, are predominantly cultivated in the semi-arid regions of the continent. Yields for local varieties are generally low, ranging from 200 to 350 kg/ha. Cowpeas are a particularly appropriate crop for limited-resource farmers because they have the ability to fix nitrogen, which improves soil fertility, and reduces the need for farmers to purchase costly nitrogenous fertilizers. In addition, cowpeas are drought-tolerant, which reduces farmers' exposure to risk.

About 85% of Africa's cowpea area is intercropped with other grains (e.g., sorghum, millet, or maize). Traditionally, farmers prefer intercropping spreading-type varieties because it helps to reduce weed populations by shading out light, thereby limiting weed growth. Intercropping also reduces insect pest populations by: 1) restricting the movement (barrier effect) of thrips, leafhoppers, and aphids; 2) through the effect of canopy shading, which increases the humidity and reduces the temperature; and 3) supporting natural predator populations which reduce cowpea pest populations.

Research to increase cowpea yields has focused on developing erect varieties appropriate for monoculture cultivation (IITA, 1992). While the recent development of higher yielding improved cowpea varieties have increased the crop's yield potential, adopting these varieties requires farmers to radically modify their traditional cropping practices. Not only must farmers monocrop these improved varieties, but they must also apply insecticide to control insect populations. If these recommendations are not followed, farmers seldom achieve the anticipated benefits of the improved varieties (IITA, 1992).

2.1.2 Utilization of Cowpeas

Cowpeas are used throughout semi-arid Sub-Saharan Africa as a food source for both humans and animals. Cowpea grain, available in a wide assortment of colors (e.g., red, yellow black, brown, purple, and white), is commonly used as an ingredient in soups, stews, sauces, and casseroles. Additionally, West Africans use cowpeas to prepare a paste which is used in fried and steamed dishes (Bergman, 1990). Green cowpea leaves are widely consumed as a fresh vegetable; and in the drier regions of West Africa, leaves are harvested, dried, and stored for later use. In some areas, cowpeas are ground into a flour and incorporated into biscuits, cookies, doughnuts, and pasta (Bergman, 1990).

Cowpea protein is rich in amino acids which are deficient in grains--making it an important complement to the grain-based diet of the poor. In addition, cowpeas are an important weaning food. Children, unable to consume sufficient bulk to meet their protein needs from grains, can meet these requirements from consuming more highly concentrated cowpea protein[1] (Ferguson and Horn, 1984). Compared to meat, cowpeas are a relatively inexpensive source of protein On a unit weight basis, it also yields almost as many calories as cereals. Finally, cowpeas are a fairly good source of thiamine, niacin, calcium and iron.

In low rainfall regions, cowpea fodder is fed to cattle, both as freshly harvested green fodder and as dry fodder during the off season (Singh and Rachie, 1985). In addition, insect and fungus damaged cowpea seeds are typically fed to chickens and other farm animals.

2.2 Storage of Grains

Households store grain for three purposes: to retain for home consumption, to trade in the market, and to retain seed for planting the following year (Hall, 1970). Storage is carried out by the producer, the trader, the processor, and the exporter, which may be the same person(s) on a low resource African farm.

In most low-resource farming communities, households depend primarily on own-production for their daily food supply. Since the harvested crop must be stored for up to a year until the next harvest, safe storage is required to insure food security. According to McFarlane (1988), 70% or more of the cereal grain produced in Africa is stored at

[1]The crude protein content of cowpea range from 23 to 30%, crude fat from 1.6 to 2.1%, and carbohydrate from 56 to 68% (Bergman, 1990). In contrast, the crude protein content of maize is 9%.

the farm level, for 6-12 months. Producers who sell part or all of their crop at harvest usually receive a relatively low price for their crop because of the abundant supply on the market. Thus, reducing storage losses has the potential to enable producers to store and then sell their commodity at higher prices when the market supply is lower.

At the village level, low-resource producers generally utilize traditional grain storage methods, which vary by region and commodity. The specific storage method used depends on such local factors as: (a) type of produce, (b) duration of storage, (c) value of produce, (d) climate, (e) cost and availability of labor, (f) cost and availability of materials and resources, (g) incidence of insect and rodent pest infestation, and (h) transportation system.

Regardless of the storage method, to minimize losses farmers must place dry, clean, uninfested grain in a sound, clean, uninfested storage container.

2.2.1 Damage vs Loss of Foodstuffs

It is important to distinguish between "damage" and "losses" to foodstuffs because each term has a different connotation and measurability. Yaciuk and Forrest (1979) define "damage" as:

> "some stage of deterioration of a foodstuff which may or may not be acceptable to the consumer. This acceptance depends on the consumer's economic level and cultural background. Certain societies discern between what can be eaten but not sold, as well as what can be eaten by some and not by others. Additionally, acceptance of a foodstuff depends on the quantities of food on hand; generally, the consumer accepts a more damaged foodstuff if his food supply is limited."

Given Yaciuk and Forrest's definition, it is difficult to measure "damage" objectively. Therefore, the following analysis focuses on analyzing "losses".

"Loss" denotes the disappearance of a foodstuff. Yaciuk and Forrest (1979) define the following types of foodstuff losses:

1) Loss of weight, which can be defined and measured accurately and economically;

2) Loss in quality, which depends on locally accepted standards and is difficult to assess unless acceptance/rejection criteria are used;

3) Nutritional loss, which can be defined and measured accurately;

4) Germinative loss, which is difficult to evaluate and is only important when grain is stored for seed or when used in processing such as brewing;

5) Loss in goodwill, which is very difficult to measure accurately. If grain is sold, the buyer expects a certain standard of product from the seller. If this expected standard is not met, the buyer may seek markets elsewhere, resulting in a loss to the seller.

Yaciuk and Forrest (1979) warn that loss, particularly economic loss, must be examined in view of the total situation, rather than as a separate entity. For example, in some West African countries, the price of cowpeas just before planting may be five times the harvest price. Thus, if a farmer incurs a physical loss of 50% by storing his/her crop until the price increases, he/she may not suffer an economic loss of 50%, but rather an economic gain of 250%.

To a farmer, loss of a foodstuff may not have the same meaning as to a scientist. While it is difficult to accurately measure the farmer's concept of loss, knowing what farmers do (and why) and the reasons farmers accept losses will help scientists to design improved storage technologies and practices. Adams (forthcoming) observed that farmers may accept losses for several reasons, including:

1) ignorance of the loss;

2) awareness of the loss, but acceptance of it as inevitable;

3) concern, but unawareness of what can be done to reduce the loss; or

4) concern, but acceptance of the loss, despite the availability of control measures.

Furthermore, even damaged grain has an economic value. For example, in West Africa, cowpeas damaged too badly for human consumption are fed to animals, which in turn are either consumed or sold by the farmer.

Therefore, efforts to improve farmers' storage methods must take into account the farmer's practices and attitudes toward foodstuff losses. For the purposes of this paper, the term "losses" will apply to changes which can be quantified (i.e. number of emergence holes per cowpea grain) by scientific means.

2.2.2 Where Losses Are Incurred

Although losses are incurred at all stages in the post-production system, including during field drying, harvesting, threshing, shelling, drying, storage, processing, and consumption, storage losses are the primary concern of this paper. The main causes of storage losses are insects, vertebrate pests (i.e. birds and rodents), molds, and fungi. According to Schulten (1988), the losses at each individual stage of the post-harvest system may be relatively small and uneconomic to reduce, but when combined they result in post-harvest losses of 10-20 percent.

Most of the literature focus on losses incurred by households storing their own-production. Yet, greater losses are possibly experienced in trader-managed commercial storage systems where grain is typically stored unprotected in bags.

2.2.3 Farm Level Storage Losses

Much of the research on improving small-farm grain storage employ surveys and trials to assess the magnitude of current losses. These data show that losses are highly variable, depend on the assessment method used, the quality of the work, and the season and regions sampled (Rukuni, 1987). Although losses vary by location and are crop specific, Schulten (1988) provides some general estimates of farm level storage losses.

According to Schulten, farm level losses, expressed as weight loss of the initial quantity stored, are in the order of 1.5% for insect losses, 0.5-2.5% for mold and 0.5-1% for rodent losses when grain is stored for up to 9 months. He also asserts that often farmers consider these losses too low to take effective action. Similarly, based on a review of the literature, Giga, Mutemerewa, Moyo, and Neeley (1991) report that farm level storage losses are generally low. For example, De Lima (1979) estimated a 6% annual weight loss due to insects and rodents in Kenya, whereas Golob (1981) reported losses of 2% in sorghum and 3% in maize in Malawi.

In contrast, Singh, Luse, Leuschner, and Nangju (1978) observed that severe losses due to the cowpea weevil have been reported in several tropical and subtropical countries. For example, Caswell (1968) found that cowpeas stored for 9 months in traditional storage containers in northern Nigeria suffered 32% and 87% damage (expressed as weight loss) when stored as unshelled and shelled cowpeas, respectively. These accounts suggest that it is difficult to generalize regarding storage losses. The magnitude of storage losses varies from region-to-region and accurate estimates for a particular case requires location and system specific analysis.

Unfortunately, most case studies reporting food stuff losses fail to describe the storage method (i.e., the storage structure or treatment the food received) under which the losses occurred. McFarlane (1988) reports a range of 4-5% for on-farm losses to stored cereal grains in Africa and states that losses in excess of the indicated range occur sporadically in both on-farm and off-farm storage. Severe losses are generally caused either by shortcomings in management or by unexpected, adverse conditions. In general, variations in farm-level storage losses are more closely related to climate than to the chosen storage technique (McFarlane, 1988). There are, however, clear differences in the nature and extent of storage losses associated with the various storage techniques. For example, storing shelled maize in woven sacks will lead to accelerated damage by grain weevils, grain beetles and warehouse moths. In contrast, storing sound, dry cobs in traditional cribs generally retards damage by these insects, while permitting greater damage by the grain moth.

The observed correlation between the magnitude of losses and storage time indicates that losses rise disproportionate to storage time increases. Yet, Richter (1988) points out that "in practice loss figures are fortunately much lower than the percentages given, because the consumption of grain is almost steady from the harvest on, thus the amount of grain stored is continually decreasing and high losses are only sustained towards the end of the storage period on a small quantity of grain."

Furthermore, Giga, Mutemerewa, Moyo, and Neeley (1991) observed that when the traditional system is disturbed by the introduction of new technologies, such as high yielding varieties (hybrids) or new pest problems, losses may increase significantly. Problems associated with newly-developed varieties include varieties that: mature before the end of the rainy season, making it more difficult to dry the harvested grain; have lower resistance to insects and molds; and have softer pods or kernels which are more prone to insect attack. Schulten (1975) observed large differences between maize varieties in terms of their susceptibility to storage pests in Malawi. He found that hybrid varieties were the most susceptible, reporting storage losses of 10% for hybrid SR 52. In contrast, widely cultivated traditional maize varieties suffered storage losses of only 1-3% and improved open-pollinated varieties incurred losses of 5%.

2.3 Insect Pests of Cowpeas

Cowpea, *Vigna unguiculata* (L.) [Walpers], like other grain legumes, are infested by both field and storage pests. Important pests found throughout its geographical range, include aphids, beanfly, leafhoppers, thrips, pod borers, pod-sucking bugs, cowpea curculio and the storage beetle (Table 2.1).

Bruchidius atrolineatus, a field pest, damages dry seeds in the pods, does not continue to damage stored seeds. *Callosobruchus maculatus*, commonly known as the cowpea weevil, is another major storage pest (Singh and Rachie, 1985; Kitch, et al., 1991). Cowpea weevil infestations begin at low levels in the field as the pods near maturity. But because of the rapid natural increase while in storage, the stored grain can be destroyed within a few months, long before the nest year's harvest (Murdock and Shade, 1991).

Adult female *C. maculatus* can lay 50-80 eggs on each pod. After the larvae hatch in about 3-5 days, they bore into the seeds, where the larval and papal stages are found. The adult emerges after about 20 days (Singh and Rachie, 1985) completing the life cycle in about 30 days. Grain damage results from larvae feeding inside the seed. After six months, Singh and Rachie (1985) report farm storage grain losses of 30% in terms of weight and up to 70% in terms of seeds infested, making the grain virtually unfit for consumption.

Table 2.1 Common insect pests of cowpeas in Africa.

Pest Status	Common Name	Scientific Name	Damage
Major Pests	Cowpea aphid	Aphis craccivora	Feeds on foliage, pods, at seedling stage
	Legume bud thrips	Megalurothrips sjostedti (syn. Taeniothrips sjostedti)	Damages flower buds, flowers
	Legume pod borer	Maruca Testulalis	Feeds on flower buds, flowers, green pods
	Coreid bugs	Anoplecnemis curvipes, Riptortus dentipes, Cavigralla tomentosicollis (syn. Acanthomis tomentosicollis), C. shadabi (syn. A. horrida), C. elongata	Feeds on green pods
	Cowpea storage weevil	Callosobruchus maculatus, C. chinensis	Damage seeds in storage
Minor Pests	Striped foliage beetles	Medythia quaterna (syn. Luperodes lineata)	Feeds on foliage at seedling stage
	Pea aphid	Aphis fabae	Feeds on foliage at seedling stage
	Other beetles	Lagria villosa, Chrysolagria spp.	Foliage feeders
	Leafhoppers	Empoasca signata, E. dolichi	Feeds on foliage at seedling stage
	Pod weevil	Piezotrachelus varius (syn. Apion varius)	Feeds on seeds within green pods
	Beanfly	Melanagromyza phaseoli	Feeds on stem at seedling stage
	Pod borer	Cydia ptychora (syn. Laspeyresia ptychora)	Feeds inside green pods
	Green stink bugs	Nezara viridula, Aspavia armigera	Feeds on green pods
	Foliage thrips	Sericothrips occipitalis	Feeds on foliage at seedling stage
	Lima bean pod borer	Etiella zinckenella	Feeds on green pods
	Foliage beetles	Ootheca mutabilis, O. bennigseni	Feeds on foliage at seedling stage
Sporadic Pests	Striped bean weevil	Alcidodes leucogrammus	Feeds inside stem and on foliage
	African bollworm	Heliothis armigera	Feeds on green pods, flowers, foliage
	Blister beetles	Mylabris farquharsoni, M. amplectens, Coryna apicicornis	Flower feeders
	Egyptian leaf worm	Spodoptera littoralis (syn. Prodenia litura)	Feeds on green pods, flowers, foliage

Source: Singh and Rachie (1985).

2.4 Traditional Grain Storage Structures

In the tropics and subtropics, food grains are mostly stored using traditional methods, which vary in their ability to insure safe storage. Performance variations are often influenced by climate, local availability of suitable materials, labor availability, investment capital, and local customs (McFarlane, 1988). The range of storage structures encountered in these regions is presented in Table 2.2.

Local experience and traditions have contributed to the development of many storage techniques. According to Richter (1988), factors which contribute to successful storage include:

(1) harvesting of grain during a pronounced dry season, which facilitates drying of the harvested grain;

(2) predominance of hard grain, which discourages insect pests;

(3) unthreshed storage, which further discourages insect pests;

(4) the use of traditionally-proven repellents such as ashes, weeds, and dusts; and

(5) storage structures which allow complementary drying, but prevent rehumidification in the next rainy season, such as good mud or pottery granaries and pits. Also, well-constructed storage structures protect the grain against flood water, rodents, and birds.

Table 2.2 Traditional/Producer Storage Structures Used in Africa.

Storage Method	Special Measures	Product
UNCOVERED		
No structure	Heaped on ground	Paddy, groundnut
Vertical pole	Tied to poles	Maize
Horizontal cords or creepers	Hung on these strands which are tied between poles or trees	Maize
Vertical racks	Hung on horizontal poles fixed to vertical poles	Paddy
Platform	Heaped on platform	Maize, pulses, groundnut
Open baskets	Raised 1 meter or more above ground	Paddy, maize, groundnut
Sacks	Placed on platform 1 meter high	Paddy
COVERED		
Horizontal grid	Hung on horizontal poles; covered with loose thatch roof	Paddy
Platform	Heaped on platform; covered with 'straw hat' which rests on platform	Paddy, maize
Granary		
(a) Simple type (usually cylindrical)	Constructed of plant material raised above ground, with thatch roof	All types
(b) Structure incorporating clay	As (a) but with mud of clay worked into floor and walls	All types
(c) Wall of clay mixed with plant material supported by timber frame	Cylindrical or elliptical, raised above ground	Cereals, paddy, millet, sorghum
(d) As (c) but not supported by timber frames	Jar-shaped, raised on "foot" of clay or log. Sometimes divided into compartments.	Maize, sorghum, millet
(e) Wall of clay only	Various shapes, "straw hat"	Cereals, groundnut
Clay jar (usually kept in living hut)	Sealed with damp earth; sealed with flat stone and clay; partially baked before storage; produce mixed with ash, jar sealed with clay; produce mixed with ash.	Maize seed, all types of grain, maize meal, maize, sorghum
Gourds	Sealed with clay; plugged with stems of plant	All types, maize, grain
Baskets	Usually placed in kitchen	Groundnut, paddy (seed), beans
Commodity wrapped in matting	Kept in living hut	All types
Stored under roof of living hut	Small bundles hung from roof above fire	Cereals
Stored on floor of living hut	Temporary storage	Paddy
Underground storage	Sometimes lined with cow dung and fired. Opening sealed with clay of grass thatch and thorns	Cereals
Communal store	Large crib of millet stalks of bamboo (12-ton capacity)	Paddy
"Improved traditional" cribs	Square sided crib with timber frame and walls of wire netting	Maize

Source: D.W. Hall (1970).

Typically food grains are first gathered on the ground to facilitate their removal from the field. Usually these heaps are only left for a few hours, or a day or two at the most. But, if the harvesting of the one crop coincides with another, the grain may be left on the ground for quite some time. Since this is a deliberate act on the farmer's part, it may be considered a temporary storage method (Hall, 1970).

In many areas, farmers temporarily store grain on platforms (covered or uncovered) as an intermediate between a granary or other storage vessel. Although unthreshed grain on uncovered platforms is exposed to the elements and various storage pests, solar radiation reduces insect pest populations for a period of time. In more humid regions, some food grains are first dried over an open fire, on a platform covered by a thatched roof.

Commonly, unhusked maize is hung in bundles between poles or trees. The maize husk serves as a natural physical barrier to many insects, especially if stored for only a short period of time.

Circular or rectangular granaries--made of plant materials, clay, or mud--are the most frequently used permanent storage structure. These are usually elevated above ground level, especially in areas where there is a danger of flood or domestic animals. The dimensions of the granaries are mainly determined by the quantity of grain to be stored.

In some countries, grain is commonly stored in compartmentalized bins. These bins are usually square, with walls about 3 meters long and 1.5-2 meters high, and are divided into four or more compartments (Hall, 1970).

In several regions in India, Africa, and Latin America farmers commonly stored grain for long periods in airtight underground pits, which are rarely opened (McFarlane, 1988; Hall, 1970; Sibisi, 1984). Richter (1988) reports that grain kept in pits may last 3 to 4 or more years, with minimal losses. Pits are typically sealed with either dung, a large stone embedded in mud, or a dry earth cap. Sometimes these pits are lined with a grass matting; while in other areas they are lined with stones or bricks and covered with clay to give a smooth hard finish. These pits are often located in enclosed areas where cattle are kept because these sites are generally free from termites and are relatively dry (Hall, 1970). While pests trapped in such a repository are asphyxiated and die quickly (Sibisi, 1984), if the moisture content is over 12-13%, grain should not be stored in an airtight container because it will mold (Lindblad and Druben, 1976).

The storage methods so far described are most appropriate for relatively large quantities of unthreshed grain. If the crop is small or grain is to be removed from the granary for food preparation, it is usually stored threshed or unthreshed in smaller containers such as small baskets or jars, which can be easily carried.

Baskets, in an infinite variety of sizes and designs, are generally used to temporarily store grain that will be used soon. When baskets are used for long term storage, they are kept in the dwelling hut or on top of other produce in a larger container or granary, usually covered with some type of matting or leaves (Hall, 1970). In many areas, households store grain in woven bags with an open mouth, made from local fibers. These containers usually have fiber or leather straps for carrying.

Farmers often store grain in calabashes, gourds or earthenware jars, sealing the mouth with clay, mud, dung, or a wooden stopper. In some countries the grain is first mixed with ash, then stored in large pottery vessels, and covered with clay/ash or stacked one on top of each other. Finally, food grains are commonly stored in the dwelling hut on lofts that are either built over the fireplace or across the whole round hut.

2.5 Traditional Grain Storage Treatments

Prior to storing the grain, farmers employ a variety of cultural, physical, and biological techniques to reduce grain losses.

2.5.1 Various Ashes and Inert Dusts

Traditionally, farmers have stored grains mixed with inert dusts made from clays, diatomite, wood ash, cow dung ash, silicates and sand to slow insect population growth. De Lima (1987) reports that mortalities result from both abrasion of the insect cuticle (resulting in dehydration) and through physical impediment when at least 20% of the produce by volume is mixed with the inert material. In addition, ashes, powder and sand reduce insect pest damage by filling interstitial spaces and/or creating a barrier to insect movement. In Ghana, mahogany ash is used to protect millet against stored products insects (Minor and Williams, 1930) and Cobbinah and Appiah-Kwarteng (1988) report that neem wood and leaf ashes reduced insect damage to stored maize. Golob and Webley (1980) observed that the effectiveness of the ash probably varies considerably, depending on the silica content of the dust and its absorptive and abrasive properties.

2.5.2 Use of Plant Materials

Throughout the developing world, farmers use a number of edible oils (e.g., groundnut, palm, copra, citrus, and coconut) and many neem derivatives (i.e., oil, ash, leaves) to protect against bruchid pests of beans, cowpeas, and pigeon peas (Mital, 1971; Schoonhoven, 1978; Singh et al., 1978). For example, in Ghana, neem oil is used as a repellent against storage pests (Tanzubil, 1991). In India, women mix split pigeon peas and other grain legumes with edible oils before storage.

Scientists have carried out numerous studies to identify the mechanisms by which these products control storage pests. Singh found that groundnut oil impedes *C.*

maculatus progeny emergence on cowpea rather than affecting oviposition or adult mortality (Singh et al., 1978). Don-Pedro (1988) reports that oils have a lethal effect on *Callosobruchus maculatus* eggs (1) by slowly reducing respiratory activity and eliminating toxic metabolites, as a result of the oil 'barrier effect'; and (2) by penetrating the eggs, which has a toxic effect. Singh et al. (1978) studied the use of edible oils and their ability to protect cowpeas from *C. maculatus* and reported that their mode of action is partially attributed to interference with normal respiration of the bruchids, resulting in suffocation. Su et al. (1972) applied oils from the peel of 8 citrus fruits to the surface of cowpea seed, and adult *C. maculatus* exposed on the treated cowpeas failed to produce progeny. Taylor and Vickery (1974) identified the principal component of citrus oil as limonene, which was found to be a highly effective insecticide. Studies by Bean/Cowpea CRSP scientists showed that storing cowpeas in a mixture of 3 parts wood ash and 4 parts cowpea provided effective protection against *C. maculatus*. The ash not only slows down adult emergence from the cowpea seed, but adults who successfully emerge have difficulty escaping from the ash and eventually die of exhaustion.

Studies have shown that some oils are more effective than others and some may have undesirable side effects. According to Singh, Luse, Leuschner, and Nangju (1978), groundnut and castor oil appeared to be superior to coconut or palm oil. Mital (1971) showed that cowpeas remained protected from beetles when treated with oil, but that such seeds lost their viability.

2.5.3 Heat and Smoke

In many locations, households store grain above a fire. Exposure to the drying effects of hot air reduces insect populations through the direct effects of heat and smoke. Under warm humid conditions, raised granaries are constructed over a slow-burning fire.

As the hot air moves through the grain, it reduces the moisture content and the smoke acts as a fumigant (Hindmarsh, Tyler, and Webley, 1978).

2.5.4 Natural Barriers and Resistant Varieties

Farmers have often selected indigenous grain varieties for their superior storage characteristics, especially those with resistant grain qualities and physical barriers to insect attack. Examples of natural barriers include the sheathing leaves of maize cobs, the pods of grain legumes and the husk of rice paddy. Breeding programs have not always recognized the importance of storage characteristics. For example, in Belize, improved maize variety Poey T66 gave higher yields, but was rejected by farmers because it was highly susceptible to weevil damage, since the sheath did not fully cover the cob (Bernsten, 1976). Recently, scientists have given high priority to breeding for improved storage characteristics. For example, in Cameroon, the Bean/Cowpea CRSP places high priority on breeding improved cowpea varieties with resistance to *Callosobruchus maculatus*, and non-dehiscent, breakage-resistant pods (CRSP, 1990).

2.5.5 Synthesis and Implications

Scientists disagree as to the efficacy of the wide variety of traditional storage methods described above. Studies by the Bean/Cowpea CRSP confirmed that in northern Cameroon ash storage of cowpeas is effective in preventing weevil population growth, if the proportion of ash to cowpea is at least 3 parts ash to 4 parts cowpea (Kitch, 1992). Golob (1984) reports that wood ash and abrasive powders, such as diatomite, provide some protection in on-farm storage, but are generally much less effective than the synthetic grain protectants. Experiments have shown that edible oils, such as palm, groundnut, and coconut are particularly effective against *C. maculatus*, which lay their eggs outside the grain (Schoonhoven, 1978; Singh et al., 1978), but less effective against *S. zeamais*, which inserts its eggs inside maize grains. Finally, Cobbinah and Appiah-Kwarteng (1988) report that neem oil reduces damage by *S. zeamais* more effectively than edible oils.

These studies suggest that before launching a major effort to reduce post-harvest pest losses, scientists must first assess the magnitude of losses farmers incur using traditional technology. This will require collecting farmer-stored samples of grain throughout the storage period and over a representative sample of sites and storage techniques.

Reducing post-harvest insect losses may require farmers to adopt a variety of pest and commodity management techniques. Where the storage period spans a wet season and a dry season, some adjustments in storage management may be needed and, at the farm level, storage structures may need seasonal modification (Golob, 1984). But unless farmers believe that losses are substantial and proposed interventions are cost-effective, few will adopt these recommendations (Rukuni, 1987).

2.6 Breeding Improved Cowpea Varieties

Prior to 1970, the international research community paid little attention to cowpea improvement in Africa. Recognizing the importance of cowpeas for limited resource farmers, both IITA and the Bean/Cowpea CRSP have focused attention on this legume.

2.6.1 International Institute of Tropical Agriculture

In an effort to increase cowpea production, the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria established a cowpea-improvement program in 1970. Initially, IITA focused primarily on germplasm collection, evaluation and maintenance, and breeding for disease resistance. Since 1980, institute scientists have placed greater emphasis on breeding for insect resistance, early maturity, improved plant types and desired seed quality. IITA hopes to develop improved cowpea cultivars, well adapted to various growing conditions and make these available to national programs (IITA, 1992). Efforts to develop insect resistant varieties are particularly appropriate for limited-resource farmers because they reduce the need to apply costly insecticides and reduce farmers' risk to pest damage.

In 1974, IITA initiated an international cowpea disease nursery (ICDN) program to identify sources of broad-spectrum, stable resistance to isolates of pathogens from many different environmental conditions (Singh and Rachie, 1985). This effort identified several cowpea lines that combined high-yielding potential with multiple disease resistance, including TVu 201(S), TVu 1190, TVu 1977, and TVu 4557 -- which were the best performers (Singh and Rachie, 1985). Similarly, sources of resistance to bruchids have been introduced into several lines including TVu 2027, TVu 11952, and TVu 11953.

In 1975, IITA established a formal cowpea international testing (CIT) program to evaluate the several breeding lines being developed through ICDN, and first sent a standardized trial, consisting of 19 entries, to 55 countries. The CIT has become a key part of IITA's cowpea improvement program and is the main channel for testing and disseminating improved materials to national research programs.

In addition to multiple disease resistance, the IITA cowpea-breeding program developed very early-maturing varieties that fit into multiple cropping systems. Because of their short duration, these varieties require fewer insecticide applications than do later maturing varieties. In addition, the Institute has developed bush-type varieties with tender pods for use as vegetables (IITA, 1992).

Although these varieties out-yielded farmers' varieties, in a recent IITA research review the Institute acknowledged that adoption of these monoculture varieties made available in the 1980s was limited, owing primarily to the continual lack of access and high cost of needed insecticides. As a result of this experience, IITA has refocused their work with current emphasis on developing cowpea germplasm that is suitable for intercropping and has high levels of insect resistance.

2.6.2 Bean/Cowpea Collaborative Research Support Program

The USAID-funded Bean/Cowpea Collaborative Research Support Program (CRSP) was established in 1980 to address major worldwide cowpea production and utilization constraints by forging linkages between Land-Grant university scientists and cowpea scientists in developing countries. The Bean/Cowpea CRSP currently supports four research projects on cowpea improvement in three African countries, focusing on breeding for pest and disease resistance (Cameroon), drought tolerance (Senegal), and integrated pest control and utilization (Ghana).

2.7 Grain Storage Technologies

In addition to breeding for insect resistances, post-harvest scientists have developed several improved storage methods and structures for (small) on-farm grain storage. These range from technologies that rely on the use of "modern" inputs such as metal drums and silos, concrete silos, plastic bags, mechanical dryers, and insecticides to improvements in the traditional methods and structures, such as lining pits with various plant materials, improved sack stacking, and sealing gourds and other containers to make them airtight.

2.7.1 Physical Disturbance

Recently, scientists discovered that the bean weevil could be controlled by physically disturbing the stored grain. Loschiavo (1978) and Quentin, et al., (1991) found that mortality of some storage weevils increased when infested sacks of stored grain where rolled or tumbled. Quentin, et al., (1991) report that brief daily tumbling of beans held in half-filled jars, buckets, and sacks reduced *Acanthoscelides obtectus* populations by 97%, relative to stationary controls. Since larvae must wedge themselves between abutting surfaces in order to successfully bore the grain, repeated tumbling of the beans prevented them from penetrating the seeds. As a result, the larvae either die of exhaustion or are smashed by the tumbling beans. Yet, hand tumbling is unlikely to be as disruptive to the cowpea weevil, *Callosobruchus maculatus*, since these larvae bore directly into the grain from eggs glued to the testa (Quentin, et al., 1991).

2.7.1 Hermetic Storage and Silos

Hermetic storage makes it possible to store grain for long periods without applying fumigants or contact insecticides, especially if bruchids are first killed before placing the grain into storage. Boxall (1974) reports that semi-hermetic conditions can be created in traditional underground grain storage pits and that it was possible to improve traditional Ethiopian storage methods by linings the underground pits with matting and straw, polyethylene sheets, sacks or concrete. Boxall reports these "linings reduced damage due to molds by restricting and preventing the ingress of water over a period of four months and also resulted in less damage due to insects and rodents" (Boxall, 1974). McFarlane proposed that metal drums, as a form of airtight storage, are "potentially more completely airtight than any underground pit" (McFarlane, 1988). In addition, McFarlane (1970) also examined gourd-storage techniques used in Kenya and showed that treating their external surface with linseed oil or varnish, greatly reduced oxygen permeability. Thus, the container can be used as a semi-airtight receptacle, if well sealed at the neck.

Storage of grain in plastic bags has also been tested as a method of airtight storage for smaller amounts of grain. Yet, because plastic can be punctured or torn easily, it is generally recommended that the plastic bags be lined with either a cloth sack or multiple layers of plastic bags (Lindblad and Druben, 1976; Kitch and Ntoukam, 1991a).

Researchers at Purdue University, in association with the Bean/Cowpea CRSP-IRA Grain Storage Project in Cameroon, devised a solar heater made of two plastic sheets--which kills 100% of all stages of *C. maculatus*, a major cowpea storage pest. They estimate that the solar heater has a useable life of two years, if properly utilized.

Finally, sheet metal and concrete silos have been recommended for small-farm grain storage. But because metal silos will rust quickly in hot, wet regions, they must be galvanized or painted regularly. In many instances, these technologies have been abandoned because their upkeep was too costly for the farmer (Richter, 1988).

2.7.2 Insecticides

Several insecticides have been used to control storage insect pests in the tropics, including permethrine, lindane, malathion, pyrethrum, dichlorvos, and phostoxin (Lindblad and Druben, 1976; Egwuatu, 1987). These insecticides are of two major types, contact chemicals and fumigant gases. As the name implies, insects must come in physical contact with contact insecticides. Contact chemicals are available as dusts, wettable powders, and liquid concentrates. Highly toxic fumigants penetrate the grain stored in stacked bags or stored in a silo and kills any infestation present (including eggs and other immature stages inside the grains). But fumigants provide only temporary control, if insects are able to reinfestation the store.

2.7.3 Critique of 'Improved' Grain Storage Technologies

While potentially successful storage techniques, plastic bags, silos, and insecticides all have various disadvantages from the farmer's point of view. In assessing the first generation of produce storage projects implemented during the 1970s and the early 1980s, Richter (1988) argues that they were poorly prepared and almost all unsuccessful. These efforts focused too narrowly on constructing farm-size silos built of cement or cemented mud bricks, and steel drums and bins, which were often expensive to construct and maintain. Also, these projects promoted the increased use of chemicals in the storage process. In contrast, according to Richter, storage projects initiated in the early 1980s were more appropriate because they began with in-depth studies of the traditional techniques and sought to improve upon these existing systems.

2.8 Effects of Storage on Nutritional Properties of Cowpeas

In addition to reducing pest losses, efforts to improve traditional storage methods need to consider their impact on grain quality. Improper storage may induce textural defect in legumes, which prolongs cooking time and demands correspondingly higher fuel inputs (i.e., hard-to-cook defect causes leguminous seeds to remain hard to eat, even after cooking for an extended time) (Sefa-Dedeh et al., 1979). Research has shown that if beans and peas are stored at elevated temperatures and high relative humidity, cells fail to separate following cooking (Jones and Boulter, 1983).

In addition to extending the cooking time and wasting fuel, the hard-to-cook effect may reduce the nutritional quality of legumes. Studies have found a negative relationship between long term storage and the protein quality and the availability of essential amino acids in beans (Molina et al., 1975; Antunes and Sgarbieri, 1979; Sefa-Dedeh et al., 1979).

2.9 Summary

Cowpeas, one of the most common food grain legumes grown in Africa, are a staple in the diets of both the urban and rural poor. Average yields are generally low because farmers face many production constraints and have limited assess to inputs needed to resolve these problems. Farmers also face storage problems for their cowpea harvest. In an effort to reduce insect pests in cowpea production and storage, scientists have employed various approaches. In addition to breeding for insect resistance, scientists have developed several storage methods and structures for on-farm grain storage. While potentially effective, many of these technologies are not economically feasible for the limited-resource farmers to adopt.

Much of the research on improving small-farm grain storage involved surveys and trials to assess the magnitude of current losses. Based on a review of the literature, farm-level losses are generally low, crop specific, and vary by assessment method, location, and season. Numerous traditional grain storage structures and protectants against insect pest damage are used to minimize on-farm storage losses. These traditional on-farm storage methods generally provide effective protection for the relatively small stores of grain low-resource farmers produce.

CHAPTER 3 COWPEAS IN NORTHERN CAMEROON

This chapter documents cowpea production and storage in northern Cameroon. The first section describes cowpea production and extension in the Far North Province. The second section describes the technical research devoted to cowpea improvement. The third section describes the 1990 cowpea production and storage survey conducted by a Purdue University research team.

3.1 Cowpea Production and Extension in Northern Cameroon

Cowpeas, the principal grain legume crop in northern Cameroon, are cultivated for leaves, grain and hay. Households harvest green leaves daily from July through the end of the rainy season, harvest green pods as vegetables from mid-July to early August and harvest dry pods beginning in late September to early October. Although cowpea production accounts for only 5% of the harvested area of the Far North Province, for many households it fills an important niche during the "hungry season" (July-August), since cowpeas are practically the only "new crop" available during this period.

Cowpea production is concentrated in the Sahel and Sudan Savanna ecology of the Far North Province. During the 1984-89 period, annual harvested area ranged from 17,000-30,000 hectares and total production from 2,211-4,560 metric tons (Table 3.1) The large amount of year-to-year variability reported in Table 3.1 may be attributable to weather, changes in cropping practices, and/or human error in data collection and compilation. Because cowpeas are generally intercropped, it is difficult to reliably estimate production. Average yields are low (300-400 kg/ha), due to insect, disease, and fertility problems. Although research trials have produced potential monoculture yields of 2,000 kg/ha, low resource farmers in northern Cameroon are often unable to obtain inputs (e.g., seed and insecticide) needed to produce high yields under monoculture.

Table 3.1 Area harvested, total production, and estimated yield for cowpea, Far North Province, Cameroon, 1984 to 1989.

Year	Area Harvested (Ha)	Total Production (metric tons)	Estimated Yield
1984	23,470	3,273	404
1985	30,232	3,118	560
1986	24,109	3,439	616
1987	16,744	2,211	424
1988	29,975	3,596	743
1989	16,998	4,560	897
mean	23,600	3,366	607

Source: National Directorate of the Agriculture Census, Cameroon.

Cowpeas are cultivated under diverse soil and climatic conditions in northern Cameroon. The NCRE's Technical Liaison Unit classified the Far North Province into three major production-system zones (Figure 3.1 and Table 3.2).

The most traditional cowpea farmers are found in the mountainous regions of Zone 1. Typically, they intercrop local cowpea varieties with either sorghum or millet and apply no insecticides. In contrast, farmers in Zones 2 and 3 are more likely to have adopted improved farming practices--including monocropping of improved cowpea varieties and insecticide sprayings.

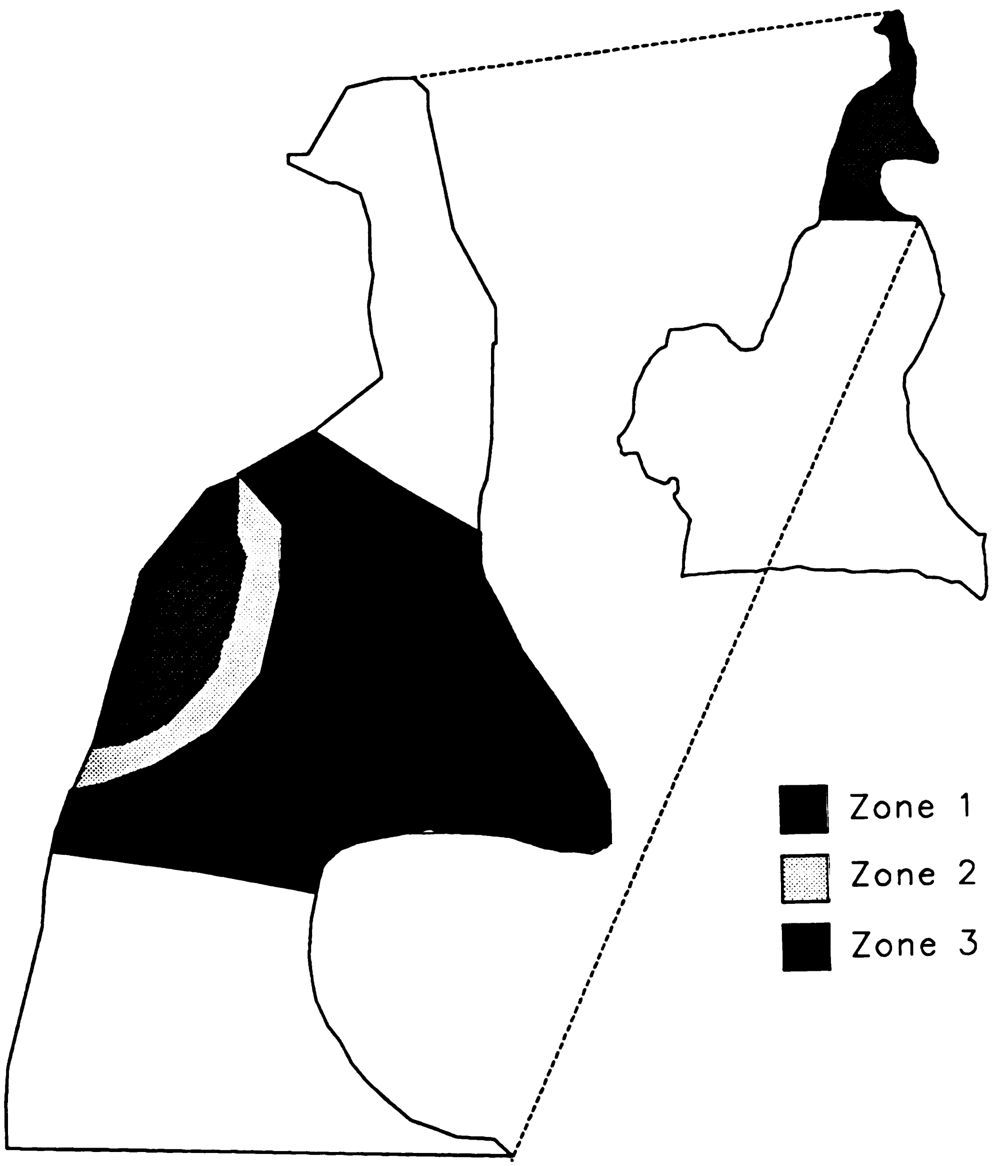

Figure 3.1 Map of the Major Production-System Zones of the Far North Province, Cameroon

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Table 3.2 Major Production-System Zones, Far North Province, Cameroon.

Zone 1
- Major crops: sorghum, millet, cowpea, peanuts
- Minor crops: *fonio, souchet, eleusine*
- Rainfall: > 800 mm
- Soils: shallow plateau soils and steep mountain slopes, erosion
- Cultivation: intensive terracing
- Animal traction: seldom used
- Population density: 80/km2
- Ethnic groups: Mafa, Mofou, Kapsiki

Zone 2
- Major crops: sorghum, cotton, peanuts, cowpea
- Minor crops: sesame, *eleusine, fonio*
- Soils: deep erodic sodic soils
- Rainfall: 700-800 mm
- Animal traction: seldom used
- Ethnic groups: Mofou, Kapsiki

Zone 3
- Major crops: cotton, sorghum, cowpea, peanuts
- Minor crops: okra, sesame, *fonio*; dry season sorghum
- Soils: loamy soils, level vertical lowlands
- Animal traction: oxen used by 25-30% of farmers
- Ethnic groups: Fulbe, Guiziga, Toupouri, Kotoko

Note: Minor crops listed in italics do not have an equivalent name in English.
Source: NCRE (1990).

Farmers in these zones are more likely to use improved cowpea technology because they grow cotton as a cash crop and thereby receive inputs and extension services from the cotton parastatal, SODECOTON. Also, SODECOTON staff devote approximately 10% of their time to providing extension services for food crops (i.e., maize, peanuts, cowpea, sorghum) and posts an extension agent (*moniteure*), in every cotton farming village. In addition, about 0.2% of the farmers participate in on-farm trials run by IRA, and receive seeds, inputs, and extension services, in exchange for their participation. In contrast, although the extension branch of the Ministry of Agriculture (MINAGRI) also provides extension for food crops, these agents are centrally located and are expected to go out to the farmers. Thus, cowpea farmers outside of the cotton villages receive minimal extension support in the Far North Province (Sterns, 1993).

3.1.1 Cowpea Consumption and Utilization

Several parts of the cowpea plant are used by the household. Cowpea leaves are an important food item for many households, which are commonly consumed as a vegetable, both green and dry. In fact, some farmers plant local cowpea varieties specifically for their high leaf yields. According to Wolfson, "leaf consumption was so important for many households that they went out of their way to provide themselves with leaves to use as a green vegetable" (Wolfson, 1989). Frequently, farmers who planted monoculture cowpeas and sprayed also intercropped cowpeas with sorghum in order to have insecticide-free cowpea leaves to eat. Other farmers reported that they consumed leaves that had been sprayed, but only after a certain number of days had past and the leaves were considered safe to eat. Cowpea leaves are also sold in local markets, at an average price of 35 CFA/kg (1984-1998) (Sterns, 1993).

Cowpea hay, an important forage resource for most households, is used for animal feed, while some also sell it in local markets at an estimated average annual price of 25 CFA/kg (1984-1998) (Sterns, 1993).

Cowpea grain is both home consumed and sold. About 24 percent of the Far North Province's cowpea grain production was sold (Census of Agriculture, 1987). Under normal rainfall conditions, average annual price for cowpea grain is 155 CFA (Sterns, 1993). Available data suggests a strong relationship between the gender of the person(s) responsible for cowpea production and their market orientation. According to Wolfson (1989), "when women are responsible for production, the primary purpose is always for consumption."

3.1.2 Cowpea Research in Northern Cameroon

Research on cowpeas is conducted by the Institute for Agronomy Research (IRA) within the *Ministere de l'Enseignement Superieur, de l'Informatique et de la Recherche Scientifique* (MESIRES). The agricultural research system is organized along major ecological zones, with one research center per zone. The Maroua center addresses production constraints for the principle cash and food crops of northern Cameroon--cotton, cowpea, millet, peanuts, and sorghum. The cowpea unit screens varieties, identifies and tests improved post-harvest storage technologies, and has recently initiated breeding to develop high-yielding cowpea varieties with resistance to storage pests. The research system is funded jointly by the Cameroonian government and donor projects. USAID's National Agriculture Research Project, implemented through IITA, has provided $46.7 million (1979-1994) through the Nation Cereals Research and Extension Project (NCRE) to support the agricultural research system, including cowpea research at Maroua. Over the period 1981-1992 the Bean/Cowpea Collaborative Research Support Project (CRSP) has provided $1.97 million through the Maroua center[2] (Sterns, 1993).

The research system in northern Cameroon employs an on-farm testing approach as a means of linking research to extension. In 1986, on-farm testing was institutionalized into the national agricultural research system when the National Cereals Research and Extension Project (NCRE) provided the impetus for the creation of the

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[2] "The NCRE program supports research throughout Cameroon, whereas the CRSP research is conducted only through the Maroua Center (Sterns, 1993)".

Testing and Liaison Units (TLU's) at four of IRA's research stations, including the Maroua Center[3] (Sterns, 1993).

The International Institute of Tropical Agriculture (IITA) works with host country institutions (IRA) and the CRSP to conduct varietal screening trials in Cameroon. Similarly, the Semi-Arid Food Grain Research and Development project (SAFGRAD) organizes varietal screening trails, which are conducted primarily on-farm but also at the research station in Maroua.

The first improved cowpea technology developed by the Maroua station was a package that included an improved cowpea variety, TVX3236 OG1 and a set of improved management practices. "This indeterminant, medium cycle (75 to 80 days to maturity) variety was selected from IITA regional screening trials for its high yield potential, grain color, and insect (thrips) resistance" (Sterns, 1993). Farmers were advised to monocrop the variety on a quarter hectare plot and apply 2-3 insecticide sprayings as needed.

Through the SAFGRAD on-farm testing program, TVX3236 was first grown by farmers in 1980, although wide-spread extension of the variety did not begin until 1984. The "TVX package" continued to be recommended and extended through the 1987 growing season. Later, "Ife Brown (a local Nigerian cultivar) and VYA (a local Cameroonian cultivar from the Moutourwa area) were added to the farmers' choice set for improved varieties in 1985 and 1986-1987, respectively" (Sterns, 1993).

During the period 1980-1986, researchers and extension workers documented significant post-harvest storage losses due to bruchid infestations. As a result, the

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[3]Farmers participating in on-farm trials run by IRA receive seeds, inputs, and extension services.

Ministry reduced the recommended plot size from a quarter to an eighth of a hectare, the contention being that until the storage constraints could be relaxed, farmers should focus on growing cowpeas as a garden food crop, rather than a cash grain crop. Sterns points out that Ministry of Agriculture and IITA researchers were at odds over this, in part, because in 1987 two new sister varieties from IITA were extended with several advantages over TVX3236: comparable yield, larger grain size, significantly less shattering of seed pods, and more importantly, greater resistance to bruchids. Available evidence suggests that these two varieties, BR1 and BR2 (IITA cultivars IT81D-985 and IT81D-994, respectively) were sufficiently resistant to bruchids to allow an additional one month of storage before bruchid damage became significant.

Summarizing the research and extension thrust since 1987, Sterns reports that "since 1987, researchers have continued to advise farmers to plant cowpea as a monocrop in quarter-hectare plots sowing BR1 and BR2 and applying 2 to 3 insecticide sprayings" (Sterns, 1993 p.39). They have also initiated two projects to address the storage problem: (1) a breeding program targeting, in part, bruchid resistance; and (2) development of low cost storage technologies which reduce or eliminate bruchid damage. Table 3.3 details the chronology of Maroua's cowpea extension recommendations.

3.2 The Bean/Cowpea CRSP/IRA Cameroon Project

The Bean/Cowpea CRSP began work in northern Cameroon in 1982, in affiliation with two host institutions, IRA and the regional cotton parastatal SODECOTON, and with the on-going SAFGRAD project. During the early years, the CRSP research focused on agronomy/pest management.

Table 3.3 Extension Recommendations for Cowpeas Northern Cameroon, 1984 to 1991.

Extended Technologies	Years Extended					
	1984	1985	1986	1987	1988	1991
Monocropped cowpeas	***	***	***	***	***	***
Insecticide sprayings	***	***	***	***	***	***
1/4 ha "block" plot	***	***	***	***	***	***
1/8 ha "garden" plot				***	***	***
Variety TVX 3236	***	***	***			
Variety Ife Brown		***				
Variety VYA			***	***	***	***
Varieties BR1 and BR2				***	***	***

"****" denotes the years in which the improved technology was extended to farmer.
Source: Sterns (1993).

In 1987, the IRA/CRSP Project initiated a grain storage project designed to address the problems of insect-caused post-harvest losses in cowpeas. The project's research objective was to devise acceptable and simple storage technologies to reduce losses to storage pests. In collaboration with IRA and NCRE scientists, Dr. Jane Wolfson conducted three surveys in major cowpea growing areas of the Far North Province to better understand farmers' cowpea storage methods and assess insect infestation in stored cowpeas. During the first survey (1987), 38 cowpea growers were interviewed. The second survey (January 1989) involved 131 interviews within 112 households. The third survey (March 1990) was conducted in 15 *arrondissements* (districts) where 117 households were interviewed[4] (Figure 3.2).

Two major conclusions from these surveys were that women have the primary responsibility for storage in most households, and that cowpea storage is generally a process--the crop is moved at least once at some time during the storage season. Insights gained from these surveys served as the basis for the subsequent research agendas and were used to develop new appropriate storage technologies.

As the IRA/CRSP Project evolved from an emphasis on agronomy/pest management to its current focus on post-harvest storage losses of cowpea, the project's breeding initiative was redirected to develop varieties resistant to storage pests, specifically *Callosobruchus maculatus*. Results from the surveys and technical research served to guide the breeding strategy. First, the surveys found that farmers in the Far North Province generally stored cowpeas in pod form for some period of time before threshing. Second, experiments found that cowpea pods can provide a substantial degree of protection against cowpea weevil, as long as the pod wall remains intact. Third, research showed that rough-seeded cowpea types provided substantial resistance to *Callosobruchus maculatus*. These results contributed to establishing the selection and breeding criteria for improved cowpea varieties: 1) combined seed and pod resistance to *Callosobruchus maculatus*; 2) non-dehiscent, breakage-resistant pods; 3) stable and higher yield under low input conditions (both in association and as monocrop); 4) dual purpose

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[4]Although 117 households were sampled, 135 samples of cowpea grain were collected because some households grew more than one cowpea variety. If a farmer grew several different varieties or stored their cowpeas using different methods, more than one grain sample was collected.

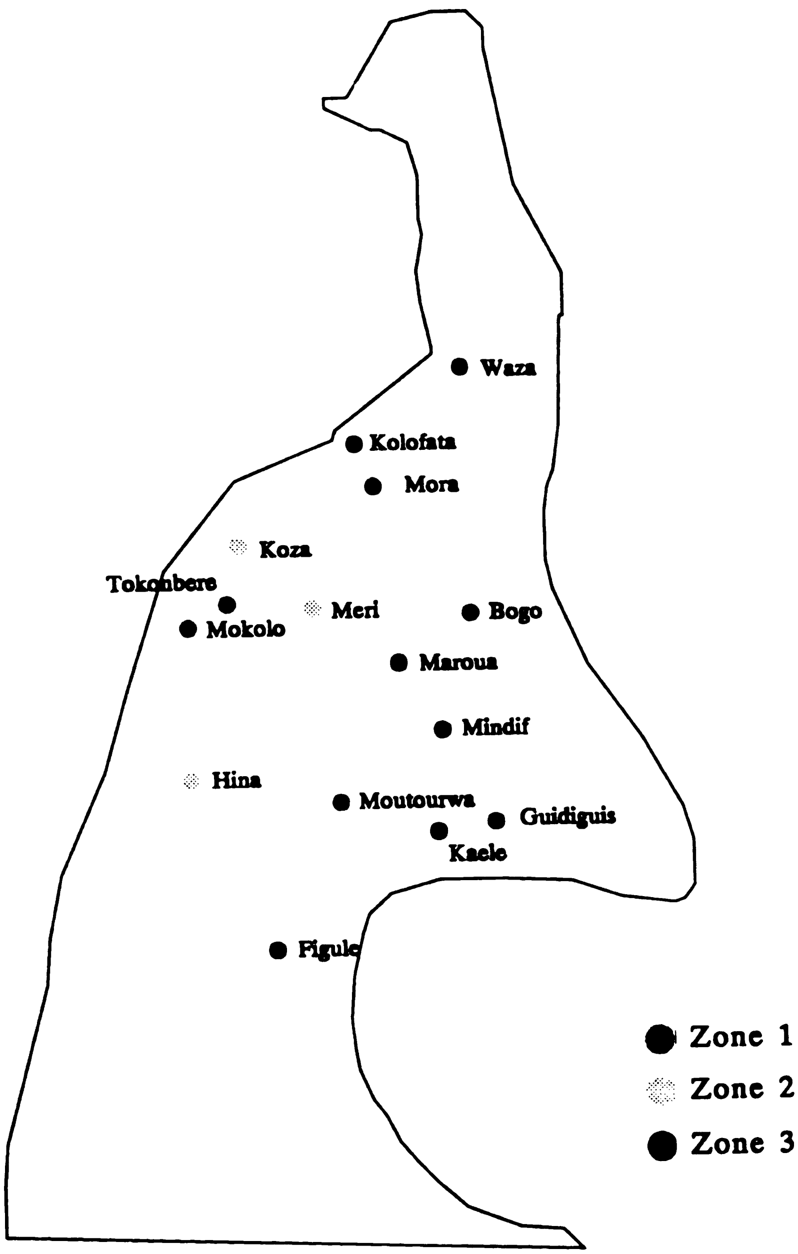

Figure 3.2. Map of Surveyed Districts (March 1990), Far North Province, Cameroon.

--acceptable forage as well as grain yield; 5) acceptable grain quality (size, color, texture, and taste); and 6) acceptable leaf quality for sauce (CRSP, 1991).

Since the mid-1980s, the IRA/CRSP project has conducted varietal trials designed to identify agronomically stable cowpea lines adapted to specific areas with tolerance to major insect pests and diseases. These trials have served as a basis for recommending varieties, as well as selection of parental material for on-going breeding efforts. Since its inception, the project has developed cowpea screening methods to evaluate resistance to storage insects, specifically *Callosobruchus maculatus*. Beginning in 1990, scientists sought to expand farmer participation in varietal improvement by modifying the way it conducted variety trials. Under the revised protocols, selection of breeding materials and varieties are based on research and farmer evaluations, rather than on yield trials alone. Research evaluations include ratings of virus resistance, pod breakage characteristics, and seed and pod resistance. Generally, material which appear promising in the field to researchers and farmers alike, are then screened for seed and pod resistance (CRSP, 1990).

3.2.1 CRSP Storage Technologies

The second component of the IRA/CRSP project focused on developing and evaluating simple storage technologies to reduce post-harvest storage pest losses--including improved bagging, storage with botanicals and ash, earthenware containers, and a solar grain heater.

3.2.1.1 Storage in Ash

<u>Overview</u>

Ash storage is commonly used by cowpea growers in northern Cameroon (Wolfson, 1987). Analysis of this traditional technology by CRSP/IRA researchers found that when mixed with ash and tightly packed, bruchid larvae will continue to develop and will pupate within the seeds as usual. However, when the adults attempt to emerge, most will have difficulty escaping from the seed and insects that successfully emerge will then have difficulty escaping from the ash.

Farm surveys found that farmers mix ash and cowpeas in various ratios. Yet, laboratory trials found that the optimal ratio of wood ash to cowpeas (i.e., maximum bruchid control) is 3 volumes of ash to 4 volumes of cowpea. Also, since female bruchids ready to oviposit will not dig downwards into ash, it is recommended that farmers cover the stored cowpeas with a 3 cm layer to prevent re-infestation. Finally, trials showed that all types of wood ash are equally effective.

Procedure

Based on these research results, scientists recommend that farmers follow the following set of protocols to improve the effectiveness of ash storage.

1) Gather enough wood ash to mix with 50 kg cowpea seed.
2) Sift ash to eliminate large particles of charcoal.
3) Mix cowpea seed with equivalent volume of ash, at a 1:1 ratio, in a large mixing bowl.
4) Pour ash mixture into a large cannary.
5) After each addition of ash and cowpeas, compact the mixture with open hands to remove air pockets.
6) When the cannary is full, cover the stored grain with a 3 cm layer of ash.
7) Each time that cowpeas are removed from the cannary, restore the ash cover.

Labor Requirements

According to Kitch, labor requirements for ash-storage of 50 kg of threshed cowpea seed are:

•	gather wood ash (50 kg),	30 minutes
•	sift out large particles,	60 minutes
•	mix and pour into cannary,	30 minutes
	total	2 hours

Capital Requirements

The only material required is a cannary.

- clay cannary (1 unit @ 1,500 CFA/unit) = 1,500 CFA

Depreciation

The estimated useful life of a cannary is 5 years.

3.2.1.2 Triple Plastic Bags

Overview

Storage in airtight containers is an effective method to eliminate *Callosobruchus maculatus* populations because they require oxygen to survive. Because clear plastic bags (50 kg capacity) are available in northern Cameroon, the project tested their effectiveness as airtight containers. Since plastic bags are easily punctured, the IRA-CRSP project suggests using three plastic bags, placed one inside of the other and individually sealed to achieve airtight conditions. To effectively control bruchids, these plastic bags must remain sealed for at least 3 months[5].

[5]This storage method is intended for mid to long term storage. It is recommended that the triple bags remain sealed for a minimum period of two months.

Procedure

Based on these research results, scientists recommend the following set of protocols:

1) Fold back the top of the first bag.

2) Place the second bag inside the first bag -- then fold the top of the second bag over the first. Repeat for third bag.

3) Fill the inner-most bag with cowpea seed, being careful to shift or rock the bags frequently to eliminate air pockets. Fill the bag close to capacity, leaving only enough room for the plastic bags to be tightly drawn together, folded back on themselves, and tied together with a cord.

4) Draw together the top plastic of the inner-most bag, squeezing tightly to press out the air. Gently rock the bag to eliminate any air pockets. Seal the bag with string or cord, twist the remaining plastic above, fold this back on itself, and tie with cord.

5) Repeat this tying procedure individually for each of the three plastic bags.

Labor Requirements

The plastic bag has a capacity of 50 kg of threshed cowpea grain. Kitch estimates labor requirements to be:

- fill plastic bags, 30 minutes

Capital Requirements

The only material required are three clear plastic bags:

- 3 plastic bags (1 unit @ 150 CFA/unit) = 450 CFA

Depreciation

The estimated useful life of a plastic bag is 1 year.

3.2.1.3 Solar Heater Technology

Overview

At Purdue University, CRSP scientists discovered that brief exposure to temperatures of 65 C° for 5 minutes kills 100% of all stages of *C. maculatus*. If the period of exposure is extended to one hour, a temperature of only 57 C° will kill all stages of the cowpea weevil.

In Cameroon, IRA/CRSP scientists devised a simple solar heater made of two sheets of plastic sheeting and an insulting "mattress" of threshed cowpea pods placed between a heat-absorbing sheet and the earth. Several different materials were tested as underlayers, including black cotton burlap, white cotton cloth, blue cotton cloth, brown burlap, beige burlap, and black plastic. Regardless of the underlayer materials, sufficiently high (over 60° C) temperatures were reached and no bruchids survived any of the treatments (Table 3.4).

To prevent reinfestation after disinfesting the cowpeas, IRA/CRSP researchers recommend storing the grain in clear plastic bags (one or two bags placed one inside the other) and sealing them with twine; or placing the grain into a clay cannary or granary (traditional storage structure covered by a thatched roof) and covering the grain with a 2-3 cm layer of ash.

Solar treatment is especially promising because it eliminates both *B. atrolineatus* and *C. maculatus* populations on cowpea seed, without affecting germination and cooking time.

Procedure

Based on these research results, scientists recommend the following set of protocols:

Table 3.4 Results of solar heater treatments on emergence of cowpea weevil by type of underlayer materials.

Underlayer materials		Temp. attained within seeds[a], C°		No. emerged adults
Color	Fabric	Mean	Range	Mean
Black	Cotton	76.8	63-84	0.0
	Plastic	76.2	54-89	0.0
	Burlap	74.1	57-79	0.0
Brown	Burlap	72.5	58-81	0.0
White	Cotton	69.7	61-76	0.0
Beige	Burlap	66.7	54-74	0.0

[a]After 100 minutes of exposure.
Source: Murdock and Shade (1991).

1) Place an insulating mattress of dried weeds or grass (3m x 3m area and 4-5 cm thick) on the soil surface.

2) Place the 3m x 3m sheet of black plastic (two 3m x 1.5m sheets sewn together) directly on the insulating mattress.

3) Spread cowpea seeds (50 kg) out evenly on the black plastic surface.

4) Cover the cowpea seeds with a 3m x3m sheet of clear plastic.

5) Fold together the edges of the black plastic and the clear plastic covering to prevent air circulation around the seeds.

6) Place small stones on the folded edges to seal the seeds into a "plastic envelope".

7) Treat the seeds for at least 2 hours around midday.

8) To prevent re-infestation, store the cowpea grain in either clear plastic bags, a cannary and covered with 3 cm of ash, or a granary and covered with 3 cm of ash.

Labor Requirements

The solar heater has a capacity of 50 kg of threshed cowpea per batch. Kitch (as per phone conversation) estimated labor requirements to be:

•	construct heater,	30 minutes
•	solar treat grain,	1 hour
•	bag grain,	30 minutes
	total	2 hours

Capital Requirements

Materials required to construct the heater include:

•	black plastic (6m @ 800 CFA/m^2)	= 4,800 CFA
•	clear plastic (3m @ 700 CFA/m^2)	= 2,100 CFA
•	sewing charges; and	= 500 CFA
•	cannary (50 kg capacity @ 1,500 CFA/unit)	= 1,500 CFA
OR		
•	plastics bags (3 bags @ 150 CFA/bag)	= 450 CFA

Depreciation

Estimated useful life of these materials are:

•	solar heater,	2 years
•	cannary,	5 years
•	plastic bags,	1 year

3.2.2 On-Farm Demonstration Results

On-farm, farmer-participation demonstrations (1990-1991) were conducted to evaluate the alternative storage technologies. Table 3.5 presents the results of the demonstrations of the various treatments in terms of the number of *C. maculatus* adult emergence holes/100 seeds. Storage losses averaged only 4% when grain was first treated using the solar heater technology and then stored in triple plastic bags. Farmer feedback on the potential usefulness of the solar technology included the suggestion that the solar heater materials could be purchased and used communally by 5 to 10 farmers. Farmers concerned about seed germination following the solar treatment were informed that research results showed no significant effect. In response to concerns about post-solar heater treatment storage, farmers were told that they must take measures to prevent subsequent re-infestation (e.g., store treated seeds in cannaries or granaries covered with a layer of ash).

Under the triple bagging technique, losses averaged 3%, slightly lower than the solar plus triple bag technology. Yet, due to the small number of replications (2) for this treatment, these results are not statistically different from solar plus triple bagging. Also, since it is technically impossible that triple bagging alone could result in lower losses than solar plus triple bagging, it is assumed that these two technologies are equally effective.

Improved ash storage was almost as effective in limiting the number of emergence holes as the solar heater plus triple bagging treatment--storage losses for the ash treatment averaged only 6%.

In contrast, under the double bagging treatment, losses averaged 9%--possibly due to punctures in the bags which broke the hermetic seal.

Finally, under the control 154 emergence holes were found in the sample of 100 seeds--suggesting 100% loss when cowpeas are stored unprotected in burlap bags for approximately 3 months or more. While some farmers store cowpeas in cloth sacks, data collected by Wolfson suggests that farmers using cloth sack storage incurred losses averaging only 14%, after 4-6 months of storage[6]. This discrepancy may be due to differences in the way farmers process and store cowpeas in cloth sacks, compared to the protocols followed for the control.

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[6]Analysis of cowpea grain samples collected from farmers who reported storing cowpeas in sacks.

Table 3.5 On-Farm Demonstrations of Improved Storage Technologies, Northern Cameroon,[a] 1990-91.

		Treatment[b]				
Village	Rep	Control (Sack)[c]	Improved Ash only	Double Bag only	Triple Bag only	Solar Heater and Triple Bag
Gatouguel	1	334	0	9	---	5
	2	---	2	9	---	6
Zouaye	1	89	3	---	---	1
	2	---	6	---	---	---
Djoulgouf	1	73	10	---	6	5
	2	---	11	---	---	5
DJJingliya	1	118	11	---	0	2
Mean		154	6	9	3	4
Range		73-334	0-11	9	0-6	1-6
Reps		4	7	2	2	6

(a) Number of *C. maculatus* adults that emerged (i.e., as indicated by holes in seeds) in samples of 100 cowpea seeds receiving different storage treatments, after approximately 3 months in store.
(b) --- indicates that the respective treatment was not treated in the respective village.
(c) The control involved placing cowpea seed in a 50 kg burlap bag without and protective treatment. This control is not however, indicative of the storage practices followed by most cowpea farmers in northern Cameroon.

3.3 Cowpea Producer Survey

In an effort to generate information to help focus the technical research project, the project sponsored several farmer surveys.

The preliminary survey (November 1987) found that most cowpea farmers both stored cowpeas intended for use as seeds for the next year's planting, kept grain to meet their household needs, and if their production is sufficient to meet the household's consumption needs, sold the surplus. Farmers cited losses from storage pests as a major problem.

The second survey (January 1989) found important gender differences in cowpea production methods, utilization, and storage techniques between the households interviewed. Women cowpea producers generally intercropped their cowpeas without using insecticides. Whereas, men generally monocropped and about one-half used insecticide. Women grew cowpeas primarily for home consumption and were more likely to be responsible for storing cowpeas intended for home consumption, while men primarily sold the cowpeas they produced. When men were responsible for storing cowpeas intended for home consumption, they used insecticides to help preserve cowpeas more often than women.

A third survey was conducted in March 1990, during which 117 households were interviewed[7]. The survey sample was distributed around the villages of Maroua, Mokolo, Kaele, south of Maroua towards Figule, near Mora, around Meri and towards Waza (Figure 3.2) which represented the three major cowpea production-system zones of the Far North Province (Table 3.2).

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[7]While 117 households were interviewed, 135 grain samples were collected. If a farmer grew several different varieties or stored their cowpeas using different methods, more than one grain sample was collected.

The procedure used to select the sample of farmers to interview differed by location[8]. First, in the large cowpea-producing areas IRA staff contacted cowpea farmers or made arrangements for a contact person to introduce them to farmers, prior to the arrival of the survey team. Second, in villages with an established relationship with the CRSP, the team went directly to a village dignitary who then introduced them to cowpea farmers. Third, the team also randomly stopped along the roadside when they saw cowpeas in storage. Finally, in villages where the team had previously conducted surveys (1987, 1989) they both contacted farmers from previous visits and meet with new farmers.

Interviews were conducted in 15 *arrondissements* (districts). The locations, villages and the number of households per village is presented in Table 3.6. In addition, samples of stored cowpeas were collected from the interviewed households and assessed for storage damage. These households had been storing
cowpeas for approximately four to six months prior to sampling[9].

3.3.1 Socioeconomic Characteristics

Although the 1990 survey respondents identified themselves as belonging to one of 19 different ethnic groups, most respondents were Mafa/Matakam (26%), Guiziga (22%), Kanouri/Bornouwa (16%), or Moufou (8%).

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[8]Since farmers were not randomly selected, statistics estimated from data collected can not be used to estimate population parameters.

[9]Most farmers had moved their cowpeas to their final storage site at the time of the survey (4-6 months into the storage season, depending on the harvesting time).

Table 3.6 Locations in which interviews were conducted and the numbers of villages and households within each location, northern Cameroon, 1990.

Zone	Location	Village (No.)	Household (No.)
Zone 1			
	Mokolo	12	19
	Tokonbere	2	3
Zone 2			
	Hina	4	8
	Koza	10	20
	Meri	7	10
Zone 3			
	Bogo	2	5
	Figule	2	6
	Guidiguis	4	7
	Kaele	3	5
	Kolofata	4	5
	Maroua	4	11
	Mindif	2	4
	Mora	5	7
	Moutourwa	2	3
	Waza	2	5
	Total	65	117

Source: Wolfson (1990).

Household size ranged from 1 to 96[10], with a mean of 12. The household generally consisted of a male head of household, his wife (wives) and their children.

3.3.2 Farm Characteristics and Management Practices

Sampled cowpea farmers (1990) followed a variety of production methods. While some farmers used only traditional technology, others used improved varieties and/or production recommendations extended by the research-extension system (Table 3.7).

Traditionally, cowpeas are intercropped with cereals in northern Cameroon. Among the sample, most of the respondents (64%) intercropped their cowpea, although

[10]The household of one chief included 30 wives and a total of 96 people. The next largest household included 54 people.

28% monocropped, and 8% plant some to both cropping patterns. Compared to farmers who intercropped, monocropping farmers planted larger hectarages (0.92 ha vs 1.24 ha) and harvested three times as much grain (82 kg vs 249 kg); while farmers planting both cropping patterns cultivated as much area (1.27 ha) as monocrop farmers, but one-half as much grain (138 kg). On intercropped fields, cowpea yields averaged 144 kg/ha (ranging between 6 to 1000 kg/ha), compared to 327 kg/ha (ranging between 22 to 800 kg/ha) on monocropped fields, and 120 kg/ha (ranging between 3 to 240 kg/ha) on farms both intercropping and monocropping.

Of the total sample, only 17% plant improved varieties. Generally, farmers monocrop improved cowpea varieties (41%), but 7% intercrop them. Among farmers who used both cropping patterns, 18% planted improved varieties, but it is not known if they are monocultured or intercropped.

Most farmers surveyed did not apply insecticide (71%), but usage varied between cropping systems. While 62% of the monoculture farmers use insecticide, 27% of farmers planting both cropping patterns, and only 15% of intercropping farmers applied insecticides. Of those farmers who do not spray insecticide, 54% stated that they were not able to obtain insecticides and 16% did not spray because they face a cash constraint.

Generally, fields with yields greater than 200 kg/ha tended to be monocropped and sprayed with insecticide, whereas fields with yields less than 200 kg/ha tend to be intercropped and not sprayed with insecticide.

Table 3.7 Farm characteristics and management practices of sampled cowpea farmers, northern Cameroon, 1990.

Characteristic of the Cowpea Enterprise		Cropping Pattern			
	Statistic	Intercrop (64%)	Mono-culture (28%)	Both (8%)	Total (100%)
Area (ha/farm)	mean (SD) range	0.92 (1.2) 0.13-8.25	1.24 (1.2) 0.13-5.0	1.27 (0.6) 0.5-2.0	1.05 (1.2) 0.13-8.25
Production (kg/farm)	mean (SD) range	82 (88.6) 4-500	249 (323.0) 18-1850	138 (74.3) 6-240	134 (198.8) 4-1850
Yield (kg/ha)	mean (SD) range	144.3 (194.4) 6-1000	326.5 (222.3) 22-800	119.8 (95.5) 3-240	200.3 (215.7) 3-1000
Use MVs (%)		7%	41%	18%	17%
Use Insecticide (%)		15%	62%	27%	29%
Household size	mean (SD) range	11 (12.9) 1-96	17 (13.0) 2-54	13 (7.8) 1-30	13 (12.8) 1-96

Source: Computed from data collected by Wolfson (1990).

3.4 Cowpea Farmer Categories and Characteristics

Social scientists investigating the adoption process seek to classify farmers into farmer types, ranging from non-adopters to full adopters of new technology. Following this paradigm, the surveyed cowpea farmers were grouped into three adoption types--non-adopters, moderate adopters, and advanced adopters--based on his or her adoption level of improved production practices (Table 3.8).

"Non-adopters" (47%) are defined as farmers who plant only traditional varieties, generally intercropping them with either sorghum or millet, and do not apply field insecticides[11]. "Moderate adopters" (31%) are defined as farmers who practice a combination of the improved package recommendations and the traditional production methods. In contrast, "advanced adopters" (22%) are defined as farmers who have made a serious attempt to adopt the recommended improved package[12] (i.e., monocropped, quarter-hectare plots of an improved variety [BR1, BR2, VYA or TVX3236] and apply insecticide).

Cowpea production responsibilities differ among households. In some households, men are primarily responsible for the production; in others, women are the primary producers, while in others, the responsibility is shared. Households where women had primary responsibility for cowpea production are mostly "non-adopters". In contrast, "moderate" and "advanced" adopters tend to share production responsibilities (Table 3.8).

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[11]Farmers planting traditional varieties do not apply insecticides, in part, because for these households, cowpea leaf consumption is an important part of their traditional diet.

[12]Some "advanced adopters" do not spray their cowpea plot with insecticide because they face either a cash or availability constraint. It is assumed that if these constraints were removed, they would apply insecticide. And some monocrop and apply insecticide to traditional varieties.

"Advanced adopter" households tend to be large, averaging 19 members, compared to "moderate adopter" households which average 13 members, and "non-adopter" households which average 10 members (Table 3.8).

Farm characteristics differ among the three categories of households. "Non-adopter" households plant the smallest area (an average 0.7 intercropped) to cowpea and harvest only 82 kg/household. In contrast, "moderate adopter" households plant on average 1.3 hectares and harvest 96 kg (28% of these households monocrop); and "advanced adopter" households plant on average 1.3 hectares and harvest 287 kg (84% monocrop[13]) as shown in Table 3.8.

Institutional access (i.e., extension and inputs) appears to be associated with the adoption of improved varieties and production practices. "Advanced" and "moderate" adopter farmers tend to live in zone 3, and are more likely to have access to extension services and inputs, either through SODECOTON or IRA, compared to farmers in zones 1 or 2. While "non-adopter" farmers live in all three zones, the majority of farmers in the mountainous regions of zone 1 are "non-adopters".

3.5 Cowpea Storage

In Cameroon, cowpeas are generally harvested in mid-to-late October after the pods have ripened and dried on the vine. To protect cowpea from bruchid damage (*Callosobruchus maculatus*)--the most common cowpea storage pest--farmers have developed a variety of traditional storage treatments and structures.

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[13]Some advanced farmers intercrop improved cowpea varieties with cotton. Insecticide applied to the cotton provides protection to the cowpea crop.

Table 3.8 Characteristics of cowpea farmer types, based on adoption level of improved production practices of survey respondents, northern Cameroon, 1990.

Characteristics	TYPE OF FARMER (N=117)		
	Non-Adopter	Moderate Adopter	Advanced Adopter
Percent of Respondents	47%	31%	22%
Social Characteristics			
Household size mean (median) (SD)[a]	10 (8) (11.9)	13 (8) (14.5)	19 (16) (10.9)
Gender[b] (F/M/B%)	44/3/53%	18/13/69%	13/13/74%
Farm Characteristics			
Area (ha/farm) mean (median) (SD)	0.7 (0.5) (0.6)	1.3 (0.63) (1.7)	1.3 (0.85) (1.1)
Production (kg/farm) mean (median) (SD)	82 (50) (87)	96 (75) (89)	287 (228) (340)
Yield (kg/ha) mean (median) (SD)	150 (68) (228)	159 (96) (172)	343 (320) (198)
Cropping Practices			
Monoculture (%)	0%	28%	84%
Insecticide (%)	0%	28%	93%
1/4 ha plot (%)	na	na	na
Improved variety (%)	0%	15%	55%
Institutional Access[c]			
Zone 1 (%)	27%	13%	6%
Zone 2 (%)	34%	28%	23%
Zone 3 (%)	39%	59%	71%

[a]SD = standard deviation
[b]F = female, M = male, B = both
[c]In general, Zone 1 farmers (mountain) had poorer access to institutional support (i.e., markets and extension), compared to Zone 3 farmers (plains) who had direct or indirect access to SODECOTON.
Source: Computed from data collected by Wolfson (1990).

3.5.1 The Storage Process[14]

The cowpea storage process is carried out in stages over time and space, as shown in Figure 3.4 [15]. The storage process begins (Stage 1) once the cowpeas are harvested.

Typically, the harvested cowpea pods are sun dried before being threshed and stored (Stage 2). Most farmers first place the cowpea pods on a drying structure called a "danki"-- an unprotected rectangular platform, raised 6-7 feet above the ground and supported by a wooden framework (Figure 3.3 [a]). Farmers reported that they stored their cowpeas on the danki from one week to over six months. Prolonged danki storage is likely due to a labor constraint. While 16% of this subset of farmers had treated their cowpea pods while still on the danki (3% ash, 7% herb, 3% insecticide, and 3% other), most farmers (84%) had applied no insecticide control treatment. Since many farmers transplant *mouskwari* sorghum, a very important crop for food insecure households, at the same time as when cowpeas are harvested, a shortage of labor likely delays more rapid threshing and storage.

When time permits, farmers remove the cowpeas from the danki and usually thresh the crop (Stage 3). Threshed grain is used for immediate consumption, sold, or moved into a more permanent second storage site.

Grain for final storage (Stage 4) is typically placed in a granary, sacks, cannaries, or drums. By March 1990, 32% of the respondents had moved their grain to a granary,

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[14]This information is based on the findings of Jane Wolfson (1990), who interviewed the household member primarily responsible for storing the household's cowpea crop, and asked him/her to describe the process he/she followed when storing cowpeas.

[15]The numbers enclosed in parentheses indicate the percentage of the respondents who followed the respective storage practice, as of March 1990 when the cowpea grain samples were collected.

25% to sacks, 13% to a drum, and 7% to a cannary, although 23% still stored their grain on a danki. Once placed in permanent storage most farmers use one or more of the following methods to protect stored cowpeas from insect pests (Wolfson, 1990):

(a) ash or ash mixed with herbs or insecticide;

(b) herb or herb mixed with insecticide, ash or water;

(c) insecticide or insecticide mixed with herbs; and

(d) other (including tobacco or roasting the grain).

Ash used for storage is derived from either cooking fires (e.g., wood and millet or sorghum stalks) or animal dung. Herbs used include mint, *mazavrik, hamas, mejevedin, casiedra, lndiya, brumida, vrad*[16], and tobacco. Furthermore, in an earlier survey, Wolfson (1987) found that some farmers treat their cowpeas differently, depending on their intended use. Cowpeas selected for seed were generally treated, especially when farmers selected next year's seed at harvest or soon after.

Granaries, the most commonly used storage method, are large round structures that are used for bulk storage; but vary in size, shape, and construction material by ethnic group. Granaries are usually divided into sections, in order to facilitate storing several different crops. In contrast to dankis, granaries are usually closed structures, although their tightness depends on the granary type (Figure 3.3 [b]).

Sack storage, the second most common storage method, involves placing grain in burlap sacks (50 kg), which are then stored in a granary or family dwelling. Generally, farmers storing in sacks (25%) did not treat their grain (66%)--possibly because they are

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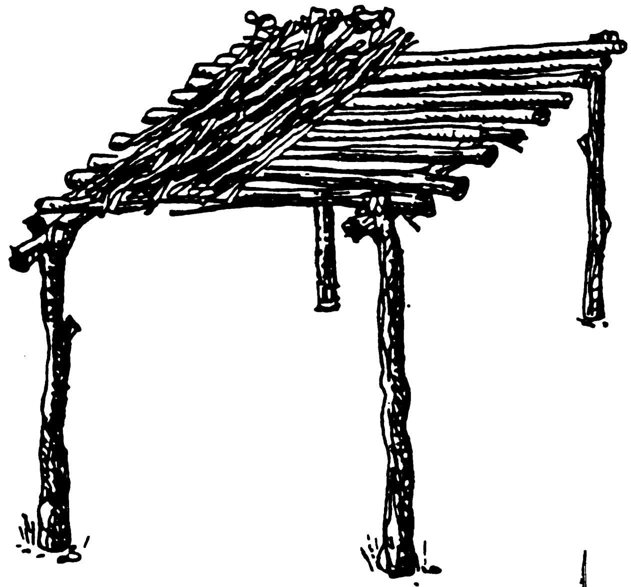
[16]Spelling is the transliteration of the spoken name.

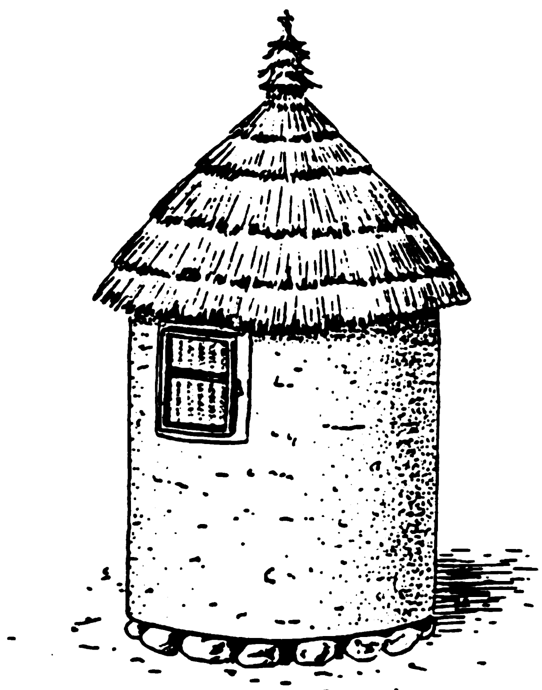
intended for immediate sale-although about one-third apply insecticide to sack-stored grain.

Drum storage, the third most common storage method, involves placing the grain in a 50 gallon metal drum and sealing it with a lid. Of the households who had moved their grain to a drum (13%), almost all (98%) applied no additional storage treatment.

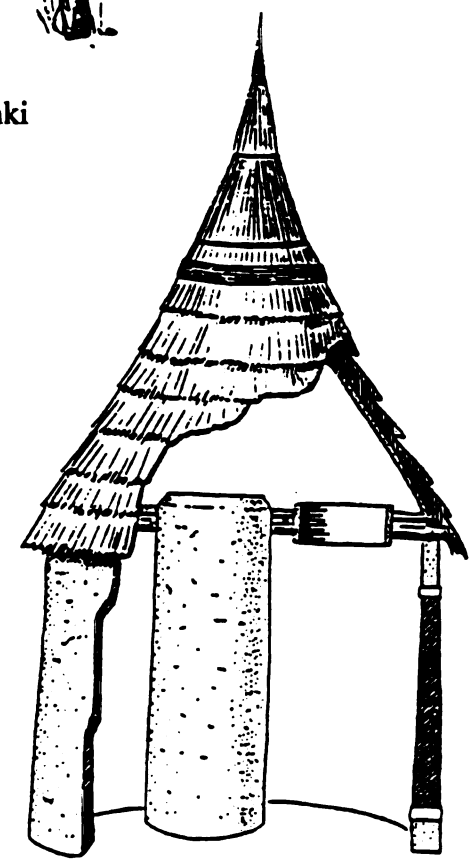
Cannaries, the least used storage method, are large clay pots, measuring about 2 feet in diameter and 1.5 feet in height, which are traditionally used to store cowpeas and other grains. Sometimes they are sealed by placing a similar or slightly smaller cannary on top of the mouth (Figure 3.3 [c]). Among households who had moved their grain to a cannary (7%) ash was the most frequently used protection method (44%).



[a] Danki



[b] Granary



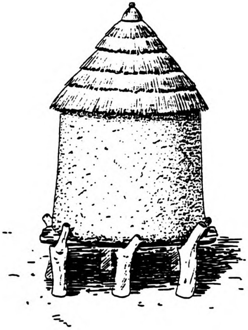
[b] Granary

Figure 3.3 Traditional Storage Technologies.

Source: Wolfson, 1989.

[b] Granary

[b] Granary



[b] Granary

[c] Cannary

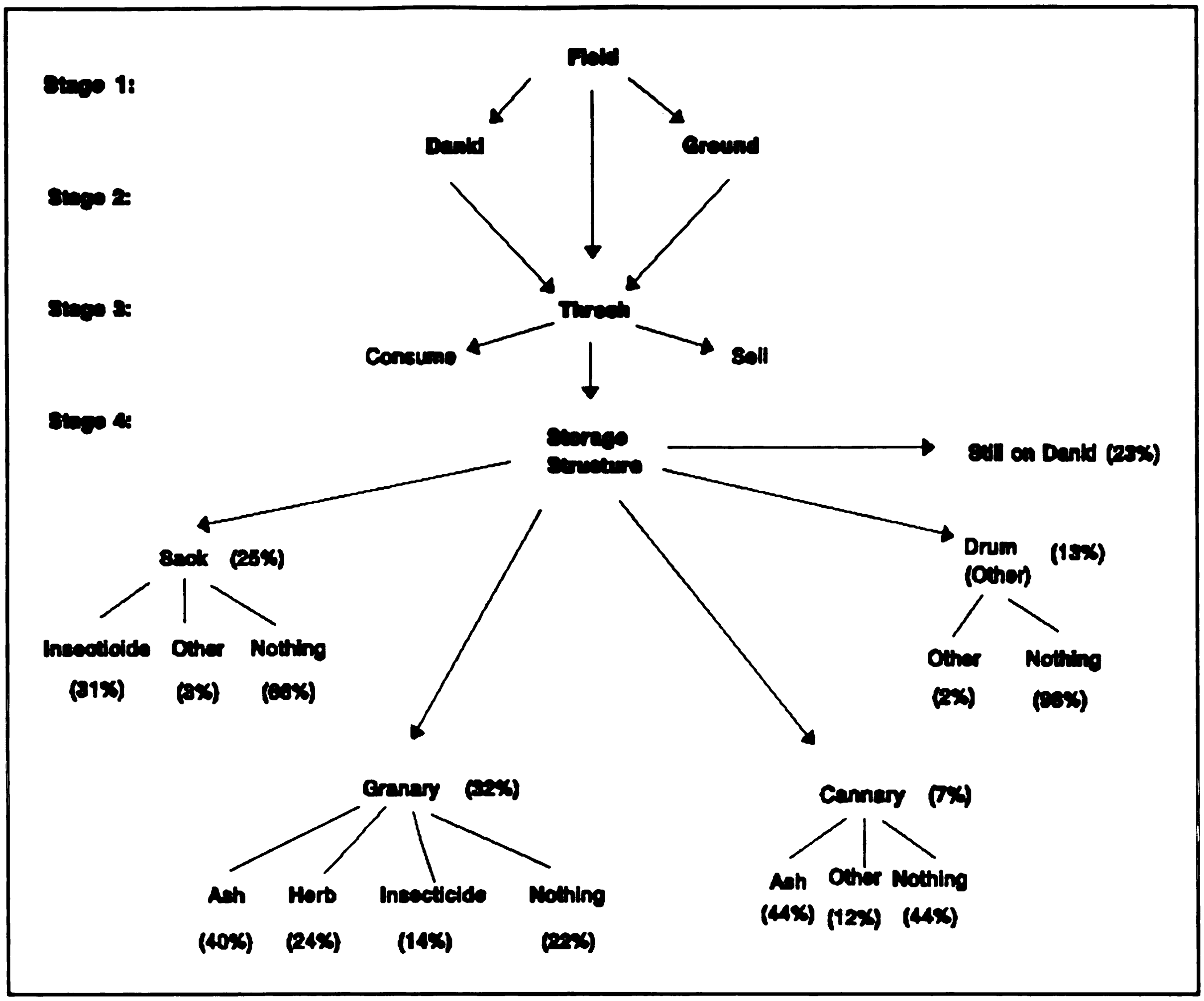


Figure 3.4. The Cowpea Grain Storage Process, Northern Cameroon.

Source: Estimated from data collected by Wolfson (1990).

3.6 Farmer Classifications and Their Storage Process

As noted earlier, the cowpea storage process is carried out in stages over time and space. Farmers first placed harvested cowpeas in one location for drying and then moved to a second location at a later date. Ash treatment (or other materials) to inhibit storage insect infestations generally occurs at the second storage site.

Figure 3.4 presents the storage process diagrammatically, and notes the percentage of respondents who followed the respective storage practices. These data indicate the location and treatment of the households' cowpea harvest, in March 1990 when the cowpea samples were collected. As of March, 23% of the farmers had not yet removed their cowpeas from the danki. While 16% of this subset of farmers had treated their cowpea pods while still on the danki (3% ash, 7% herb, 3% insecticide, and 3% other), most farmers (84%) had applied no insect control treatment. Generally, farmers did not treat cowpea stored in sacks--possibly because these were intended for immediate sale. For cowpeas placed in a granary or cannary as the final storage site, ash was the most frequently used treatment; followed by herb for cowpeas stored in the granary and no treatment for grain stored in a cannary. Where drums or other vessels (i.e., pans) were used to store cowpea seed, 98% of the time the seed was not treated. Analysis of household storage practices at the time of sampling by farmer classifications (advanced, moderate, and non-adopter) showed several significant relationships (Table 3.9).

Among households classified as "non-adopters", women were generally responsible for storage. For these households, most of the crop was either still in pods on the danki (28%), or had been threshed and moved to a granary (37%). Ash was the most frequently used treatment by "non-adopters" who had moved their grain to a granary. Furthermore, "non-adopters" as a group, almost exclusively used ash to protect their stored cowpeas.

Among "moderate adopter" households, the data did not show any discernable evidence of a gender difference regarding storage responsibilities. Many (28%) of these households still had cowpea pods on the danki; and of those households who had moved their cowpeas from the danki, 21% stored their cowpea grain untreated in sacks, 31% stored in granaries, and 18% stored in other containers including cannaries. In contrast to the "non-adopters", most (69%) of these households did not treat their stored cowpea grain.

As was the case with the "moderate adopters", the data did not show a distinguishable gender difference for "advanced adopter" households. By March 1990, most advanced adopters (93%) had removed their cowpeas from the danki and placed them into a second storage site. "Advanced adopters", as a group, most frequently used insecticide (38%) in storage, primarily spraying cowpeas stored in sacks (32%).

3.7 Farm-Level Storage Losses

Foodstuff storage losses can be measured as a loss in quality, nutritional value, or germinative ability. When evaluating storage losses at a point in time, a strict definition of loss should be applied to assess cowpea storage losses, if the seed is to be planted in the following year since the cowpea's germinative ability is destroyed approximately 30% of the time the seed coat is damaged (Kitch interview, 1992). But if cowpeas are intended for human or animal consumption, a less strict definition could be applied. While one hole in the cowpea seed coat will affect the nutritional value of the seed and may affect the food quality, this does not render the grain unfit for consumption.

Table 3.9 Storage Practices at the Time of Sampling by Farmer Classification.

	Advanced	Moderate	Non-Adopter	Total Sample
Responsible for Storage:				
solely women	32%	38%	58%	46%
shared by women and men	29%	26%	15%	21%
Location of Grain (March 1990):				
On danki in pod	7%	28%	28%	23%
In final store	93%	72%	72%	77%
Long Term Storage Method/Treatment:				
Sacks untreated	19%	21%	10%	15%
Sacks treated	32%	2%	6%	12%
Cannary with ash	0%	0%	6%	3%
Granary untreated	6%	8%	6%	7%
Granary treated	16%	23%	31%	24%
Other	20%	18%	13%	16%

Source: Computed from Wolfson (1990).

The only available data for estimating farm-level storage losses was collected by Wolfson (1990) who collected samples of cowpea that the interviewed households had stored for approximately four to six months. Each sample consisted of 50 pods (if cowpeas had not been threshed) or approximately 400 mls of grain. These samples were placed in cloth bags and taken to the laboratory where ten pods were evaluated for breakage. For the pod samples, eggs laid on the pod were counted and attributed to either *Callosobruchus maculatus* or *Bruchidius atrolineatus* according to their location on the pod. After counting the number of emergence holes in the pods, the pods were opened and the grains were assessed for losses. Wolfson recorded the number of grains in the sample, the weight of the grains and the number of emergence holes per grain. Then the sample was placed in a cloth bag and closed tightly. Thirty-five days later, the sample was frozen and again assessed for losses by recording the number of holes, the number of grains, the weight of the sample and the number and species of emerging bruchid adults.

Bruchid populations grow exponentially over time therefore, to measure cowpea storage losses[17] this study uses "the percent of seeds with 1 or more holes" as the operational definition for "percent loss", calculated as:

$$\%\text{Loss} = \frac{100-(\text{number of cowpeas with holes})}{\text{total number of cowpeas sampled}} * 100 \qquad (3.1)$$

These analyses showed that after four to six months of storage under farmers' storage practices, losses[18] averaged 12.6%, with a standard deviation of 18.0 for all households at the time of sampling[19].

To evaluate differences in storage losses among "non-adopter", "moderate adopter", and "advanced adaptor" farmers, these data were reevaluated by farmer type. These analyses showed that the level of storage losses differed greatly among the three farmer categories. "Non-adopters" incurred the highest level of losses, averaging 15.3% (S.D.= 11.9), compared to "moderate" and "advanced" adopters who averaged losses of 10.8% and 7% (S.D. = 11.4 and 17.6), respectively.

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[17]Data collected from surveyed households in March 1990.

[18]Losses reflect the level when first collected, not 35 days later.

[19]This loss level was significantly lower than the level observed in the storage trial, where losses averaged 100% in the control (sack storage) after approximately 3 months of unprotected storage.

3.7.1 Storage Losses and Farmers Field Practices

To determine if farmers' field practices affected the level of storage losses, the loss data were reanalyzed by practices followed (Table 3.10). First, these results indicated farmers who had sprayed insecticides on their standing crop (N=39) had an average of 10.3% (S.D.= 16.6), while those not spraying (N=95) had average losses of 13.7% (S.D.= 11.7) at the time of sampling. Second, storage losses and infestation levels were associated with the cropping pattern followed. Cowpeas intercropped with cotton (N=19) had the lowest level of loss, averaging 9.8% (S.D.= 9.0)--slightly lower than cowpeas planted as a monocrop (N=37), which averaged 10% losses (S.D.= 17.3). This is probably due to the fact that cowpeas which are either monocropped or intercropped with cotton were most likely sprayed with insecticide. In contrast, stored cowpeas that were intercropped with a food crop (N=78) incurred higher losses, averaging 14.7% (S.D.= 11.9).

Finally, there was a relationship between storage losses and the region where the sample was collected. The highest levels of loss (13.3%, S.D. = 8.0) were observed in samples (N=24) taken from farmers living in the mountainous west and northwest region of northern Cameroon (zone 1). In contrast, the samples from plateaus (N=41) or flat plains (N=69), (i.e., zone 2 and zone 3, respectively) had lower levels of storage loss, averaging 12.2% and 12.7%, respectively (S.D. = 10.1 and 16.3).

Thus, these results suggest there are a multitude of compounding factors which appear to influence storage losses and insect populations, including agro-climatic conditions (i.e., variations in rainfall and temperature patterns), cropping pattern, the presence of alternative hosts, and the distribution of cotton production. This last factor may be the most significant because SODECOTON is the primary source of insecticides

Table 3.10 Storage Losses by Influential Field Practices.

Factor	**Sample Size**	**Losses (%)**	**Standard Deviation**
Insecticide Use in Field:			
Spray	39	10.3	16.6
No spray	95	13.7	11.7
Cropping Pattern:			
Intercrop with cotton	19	9.8	9.0
Intercrop without cotton	78	14.7	11.9
Monocrop	38	10.0	17.3
Region:			
Zone 1	24	13.3	8.0
Zone 2	41	12.2	10.1
Zone 3	69	12.7	16.3

Source: Calculated from Wolfson (1990).

for much of the Far North Province.

3.7.2 Storage Losses and Storage Methods

To determine if storage losses and insect infestation levels vary with the storage method practiced, the data were reanalyzed by post-harvest treatment. Over one-half of the cowpea samples were not treated[20]. Among treated samples, ash, herbs, and insecticides were the most frequently used protectants (Table 3.11). As expected, storage losses varied both within and between treatments. Farmers treating their store with insecticides (N=17) achieved the highest level of protection, with an average loss of

[20]Figure 3.4 presents the various treatments that the farmers employed and their frequency of usage.

7.5% (S.D. = 8.6), but herbs (N=12) were almost as effective, averaging 8.2% loss (S.D. = 8.2). In contrast, storage in ash (N=19) provided the least amount of protection against insect losses, with losses averaging 14.7% (S.D = 11.0). Interestingly, losses in cowpea pods stored on a danki were lower than losses under storage in ash (11.8%, standard deviation =10.7). This may be because the cowpea pods provide resistance to the bruchids' penetration and the sun may inhibit insect population growth, thus contributing to the success of storage on a danki. These results indicate that either ash provides minimal storage protection, or that farmers do not effectively practice ash treatment.

Table 3.11 Storage Losses by Type of Treatment.

Method	Sample Size	Losses (%)	Standard Deviation
No Treatment	34	16.9	19.1
Insecticide	17	7.5	8.6
Herbs	12	8.2	8.2
Ash	19	14.7	11.0
Danki in pods	28	11.8	10.7

Source: Calculated from Wolfson (1990).

3.8 Economic Value of "Lost Grain"

The previous analysis defined loss as the percent of the sample of cowpea grain that had been penetrated by bruchids. Yet, farmers seldom discard grain that scientists, using this definition, would classify as "lost". Wolfson looked at peoples' perceptions and behaviors towards heavily damaged cowpeas and found that 37% fed them to animals, 24% sold them, 24% said that they could be eaten quickly, 20% throw it away, and 7% treat it with insecticides (Wolfson, 1987).

3.9 Summary

Cowpeas are the primary grain legume crop grown in northern Cameroon. Several parts of the plant are used by the household. Cowpea leaves, grain and hay are both home consumed and sold. Although research trials have produced monoculture yields of 2,000 kg/ha, average yields tend to be low (300-400 kg/ha). Part of this yield difference is due to the fact that farmers typically intercrop cowpeas with grains, which makes direct comparisons inappropriate. On the other hand, due to the inability of low-resource farmers to obtain inputs (i.e., seed and insecticide) needed to produce high yields under monoculture conditions, adoption of the high-yielding varieties is limited.

Research on cowpeas has focused primarily on developing improved varieties with storage-pest resistance and on-farm grain storage technologies. To better understand constraints facing farmers the Bean/Cowpea CRSP conducted three farmer surveys which revealed several variations exist in production, utilization, and storage methods among cowpea farmers in northern Cameroon.

Sampled cowpea farmers were classified as "non-adopters", "moderate" and "advanced adopters" of improved field practices for cowpea production. A large proportion of cowpea farmers (47%) were found to plant only traditional cowpea varieties, generally intercropping them with either sorghum or millet, and do not apply insecticide in the field. Generally these farmers were women who produced on average less than 100 kg of cowpeas, which are most likely for home consumption. When women were responsible for storing the cowpea harvest, ash was frequently used to protect their stored cowpeas.

Approximately one-third (31%) of cowpea farmers practice a "mixed bag" of cropping practices (i.e., monocropping traditional varieties without applying field insecticides; intercropping improved varieties without applying field insecticides; intercropping traditional varieties and applying field insecticides). These farmers were either men or women who produced on average less than 100 kg of cowpeas, which are most likely for home consumption.

A minority (22%) of cowpea farmers adopted improved cropping practices--planting a monocropped improved cowpea variety and applying field insecticides. These farmers produced on average 287 kg of cowpeas per household. These farmers, as a group, used insecticide the most frequently to protect their stored cowpeas.

The level of storage losses differed significantly among farmers and their field practices. The application of field insecticides was found to affect the level of farmers' storage losses. Farmers using insecticides in their fields tended to live in the plains or plateaus (zones 2 and 3) of the Far North Province and had lower storage losses. Cowpeas either intercropped with cotton or monocropped had the lowest level of loss.

Storage losses also varied with the storage method practiced. Farmers treating their store with insecticides incurred the lowest amount of storage loss and cowpeas stored in ash received the most damage. Finally, losses in cowpeas stored on a danki provided approximately the same level of protection as ash. This may be because cowpea pods provide resistance to bruchids' penetration and the sun may inhibit insect population growth.

CHAPTER 4 METHODOLOGY

4.1 Introduction

A major objective of agricultural research in developing countries is to develop new technologies appropriate for limited resource farmers. This study focuses on assessing the socioeconomic viability of cowpea grain storage technologies, either developed and/or promoted by the IRA/CRSP project in northern Cameroon, including improved ash storage, triple bagging, and a solar heater in combination with triple bagging.

Careful measurement of the economic benefits of these new technologies is needed to help guide future research efforts to develop appropriate technologies that meet the needs of limited resource farmers. This study uses the benefit-cost analysis approach to evaluate storage technologies developed by the project.

4.1.1 Economic Concepts Relevant to Benefit-Cost Analysis

Benefit-cost analysis incorporates several socioeconomic concepts, including: opportunity cost, discounting, changes in product price over time, input cost, economies of scale/size, farmer implementation of technology, partial budgeting, harvest draw-down, credit availability, and minimal acceptable return.

Opportunity Cost

In situations where households contribute their own resources to product an output, these resources must be valued at their opportunity cost. Opportunity cost is defined as the benefit foregone by using a scarce resource for one purpose, instead of for its next best alternative use. Resources that are scared or limit production have a positive opportunity cost. In contrast, resources that are plentiful or lack an alternative use have a zero opportunity cost.

Opportunity Cost of Capital

Similarly, if family capital (savings) is used to purchase inputs, it must be valued at its opportunity cost to reflect the potential income lost. Typically, the local informal credit rate is used as a proxy for the opportunity cost of capital. Empirical studies in Sub-Saharan Africa indicate that the opportunity cost of capital is sometimes as high as 2,273%, due to very high operating and transactions costs (Lowenberg-DeBoer, Abdoulaye and Kabore, 1993).

Discounting Principle

Discounting is a procedure used to take into account the time value of money. Clearly, the opportunity to earn a dollar today is worth more than an alternative that provides an opportunity to earn a dollar tomorrow. If an investment decision affects costs and revenues at future time periods, all costs and revenues must be discounted to present (current) values before a valid comparison of alternatives can be made. Typically, economists use a discount rate that is equal to the opportunity cost of capital. For example, a $1 invested at the beginning of the year (day 1) at 20% interest would be worth $1.20 at the end of the year (day 365). Similarly, a $1 earned at the end of the year is worth only $0.80 today.

The general formula used for estimating the present value of a benefit stream to be received in the future is (Gittinger, 1982):

$$V=\sum_{n=1}^{N} \frac{R_n}{(1+i)^n} \tag{4.1}$$

where V = net present value of future income

R = dollar amount to be received in future period n

i = rate of interest per time period

N = number of time periods covering the life of the investment

The formula can also be written as:

$$V=\frac{R_1}{(1+i)^1}+\frac{R_2}{(1+i)^2}+\frac{R_3}{(1+i)^3}+...+\frac{R_n}{(1+i)^n} \tag{4.2}$$

Product Price Over Time

For most agricultural commodities in developing countries, output prices vary considerably over the year. First, real prices may vary over several years as a result of both supply and demand conditions and policy changes (i.e., changes in government support prices and devaluation). Historical price data are typically used to estimate future input and output prices. Second, over a given year, seasonality effects agricultural prices. The price farmers receive for their crop at harvest is generally lowest because of the abundant supply of the crop available on the market. Over time, as supply decreases and if demand (d_1) for the crop remains strong, the price is bid up (Figure 4.1). Over time, the supply curve shifts upward (s_1 to s_3) as stocks are depleted. As a result, the market price rises from p_1 to p_3.

Input Cost

An input is defined as a good (such as cannaries for storing grain) or service (such as agricultural labor) used to produce (preserve) an output such as cowpeas.

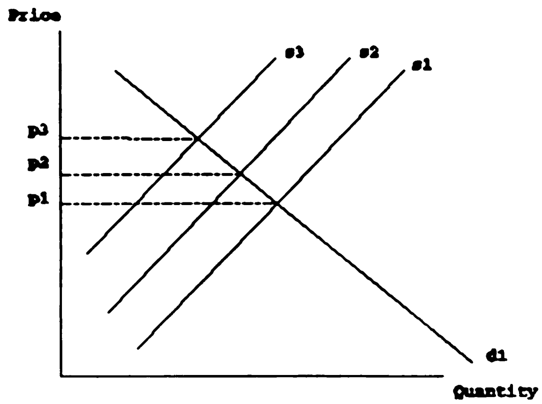

Figure 4.1. Effects of Declining Grain Stocks on Market Price

Economies of Size

A fundamental consideration in cost analysis is the relationship between unit cost and volume of output. To what extent does average total cost per unit of output change as output increases? Economies of size refers to the declining unit cost relationship that characterizes the use of equipment, machinery, and other durable assets, that result from spreading the fixed costs over a greater production base.

Farmer Implementation of Technology

Trials conducted by researchers typically indicate larger benefits than when the same technology is implemented by farmers. This result is due to the observed phenomena that farmers typically do not capture 100 percent of the potential benefits because they do not--or are not able to--implement recommendations in precisely the same manner as prescribed in recommendations (CIMMYT, 1988). For example, in evaluating new technology, CIMMYT economists typically discount the experimental yields of new varieties by 10%.

Experimental Control

In evaluating new technology, the potential benefits must be compared to the benefits farmers would earn using their own technology. Thus, gross benefits to a new technology are calculated as the difference between benefits earned by farmers using the new technology, compared to benefits using their own technology.

In conducting on-farm trials, particular care must be paid to insuring that the control actually represents (replicates) farmers' typical practices. On-farm trials that incorporate "atypical" farmer practices (e.g., zero fertilizer as the control in a fertility trial) will show higher returns to the experimental treatments that farmers would achieve, if they abandoned their current practices and adopted the recommendation.

Partial Budget

A partial budget seeks to assess the value of cost and revenue items (including opportunity cost) that change as a result of an investment decision (Gittinger, 1982). Thus, cost and return items that do not change are ignored because they will not influence the profitability of the technology. For example, consider the case of the cowpea farmer who produces primarily for home consumption, may sell some of his harvest in a surplus year, and is contemplating investing in improved storage technology to decrease grain storage losses due to weevils. In analyzing this decision, cost and return items associated with cowpea production may be ignored. Whether or not the farmer should invest in a storage technology will depend on the increase in net benefits (increased revenues minus increased costs) for each storage method, compared to his current method.

Partial budgeting is appropriate when an activity can be added to on-going farm processes without seriously reducing the resources available for other farm activities.

Since the new storage technologies to be analyzed in this study do not compete for labor resources used in other production activities, partial budgets are appropriate for evaluating their profitability[21].

Minimum Acceptable Return

In order for a farmer to be willing to adopt a new technology, it must generate a minimum return to his/her investment to justify the effort required (i.e., transactions cost) both to learn and implement the new practices and compensate him/her for the risk associated with adoption (i.e., variable performance).

Experience and empirical evidence have shown that farmers generally will not adopt a new technology unless it gives a 50-100% return to his/her investment (CIMMYT, 1988).

Stock Draw-down

Subsistence farmers, like the cowpea farmers in northern Cameroon, primarily produce cowpeas to supply home consumption requirements until the subsequent harvest. In addition, they may sell a portion of their crop to meet immediate cash needs at harvest or sell grain throughout the year. A common problem facing cowpea farmers--both for grain stored for home use and future sales--is insect pests damage to stored cowpeas, especially if the grain is stored unprotected. This consumption pattern has an important impact on the farmers' decision as to which storage method he/she will use to protect the stored cowpea from weevil infestation. For example, if a farmer produces only enough cowpeas to meet family consumption needs, he/she will be most interested in a technology that allows him/her to withdraw family food requirements on a daily

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[21]Technologies that are labor intensive and compete for resources used in other production activities are evaluated using whole farm budgeting.

basis. If he/she produces a surplus and has other sources of cash, he/she may have greater interest in a technology that makes possible safe on-farm storage until the market price is highest. On the other hand, if the farmer has no other source of cash, he/she may choose to sell at harvest--which requires no improved storage technology.

Credit Availability

Because farmers in developing countries face cash flow constraints, they typically need credit to purchase inputs required to implement new technologies. Because credit represents a cost, it must be included in estimating the returns to new technology. Farmers may borrow money from a money lender at high interest rates (often 3-10% per month), borrow from lending societies[22] at rates varying from 0-100%, or from institutional sources (i.e., government) at subsidized rates, typically 12% per year. Furthermore, if credit is unavailable, they may forego purchasing the new input, even if it is financially profitable.

4.2 Benefit-Cost Approach

Benefit-cost techniques are used to assess the financial and economic returns to an investment (Gittinger, 1982)[23].

4.2.1 Average Benefit-Cost

Average benefit-cost is typically used to compare the rate of return to two or more alternative investments. This analysis generates a benefit-cost ratio (the present

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[22] *Tontines* are informal credit associations in northern Cameroon, lending at rates varying from zero to over 100% (Conversation with Doyle Baker, 1993).

[23] In financial analysis, inputs and outputs are valued at their market prices. In economic analysis they are valued at their economic prices (i.e., inputs exclusive of subsidies; outputs at border prices). If inputs are not subsidized and outputs are not traded internationally, financial and economic analysis give the same results.

value of the benefit stream divided by the present value of the cost stream), which is interpreted as the percentage increase in returns, above the investment cost. This technique is the standard method used by the World Bank and other lending agencies to assess the economic feasibility of alternative investments.

4.2.2 Marginal Benefit-Cost

Marginal benefit-cost analysis combines partial budgeting and benefit-cost procedures to assess the incremental profitability of a new technology.

Marginal benefit-cost is appropriate if the analytical objective is to compare the profitability of several alternative investments against each other. The marginal rate of return for each investment indicates the additional return (%) a farmer can expect to gain, on the average, in return for his/her investment when he/she adopts a new technology (or set of practices), above the return from the previously most profitable technology (CIMMYT, 1988). The differences between average and marginal benefit-cost are illustrated by the following example.

Suppose investment A costs $20 and net returns are $40 and investment B costs $30 and net returns are $45. The average rate of return on investment A and B would be 200% and 150%, respectively. On the other hand, the marginal rate of return on investment B (i.e., $30-20/$45-40) is 50%. In other words, the additional $10 required to invest in technology B generates a 50% rate of return above investment A. Hence, if a 50% ROR is acceptable to the farmer then it would be reasonable for the farmer to invest in technology B, otherwise the farmer should only invest in technology A.

Since marginal benefit-cost analysis is a type of partial budget analysis, it only considers the cost of inputs (i.e., materials, labor and machinery) and the value of output which vary from treatment-to-treatment. In the case of a storage technology, the benefits (returns) are calculated by multiplying the amount of foodstuff saved (i.e., loss reductions) times the market price per unit of output saved. The cost of the variable inputs are determined by multiplying the amount of each input used by its market price.

Dominance Analysis

A dominance analysis is carried out by listing the alternative investments in order of increasing costs that vary. Any investment that has net benefits that are less than or equal to an investment with lower costs that vary is dominated. The dominance analysis shows that the value of the increase in net benefits (i.e., grain saved in storage) is not enough to compensate for the increase in costs.

4.2.3 Sensitivity Analysis

A major weakness of traditional benefit-cost analysis (both average and marginal benefit-cost analysis) is that it ignores the effects of variable outcomes. By using "average" values for inputs, outputs, and technical coefficients, it assumes all farmers face similar opportunities and constraints. In practice, the economic outcome of using a technology is variable, owing to differences in farmers' environment, resources, managerial skills, and similar factors. Variability in outcomes introduce risk into farmers' adoption decisions. The greater the expected variability (risk) in outcome around an expected net return from a particular technology, the less likely a farmer will adopt it.

Although the expected variability is difficult to assess a priori, approximate values can be estimated by analyzing the dispersion around the individual levels of inputs, outputs, and technical coefficients on which the average costs and benefits figures are based. By substituting these alternative values for the average values, sensitivity analysis provides a tool for evaluating the differences in net returns associated with differing levels of inputs, outputs, and prices that farmers may face.

Farmer "Types"

Traditional benefit-cost analysis evaluates technologies by comparing the profitability of each treatment, based on a single set of cost and benefit data, which implicitly assumes that all farmers have equal access to resources (land, labor, and capital), the same tastes and preferences, similar aversion to risk, and equal access to credit and output markets. Based on these assumptions, a technology that gives a sufficiently high net return is recommended to all farmers. While the concept of recommendation domain[24] is often used to refer to farmers with similar circumstances, this concept is seldom developed to fully reflect the way in which these differences affect technology adoption.

Thus, traditional benefit-cost models often fail to analyze how farmer-to-farmer differences in resources, cultural preferences and institutional access affect profitability. Missing "determinants of adoption" may include differences between farmer "types" ("non-adopter"[25], "moderate adopter", and "advanced adopter" with respect to management practices, capacity to bear risk, access to credit and extension services, and access to both input and output markets. These factors are considered in the following analysis to fully assess, ex ante, the likely profitability of various grain storage technologies to different types of farmers.

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[24]Recommendation domain refers to groups of farmers who are relatively homogeneous with respect to resources and other circumstances.

[25]"Non-adopter" farmers are "traditional" farmers in the following rate of return analysis to the improved storage technologies.

4.3 Factors Affecting Technology Adoption: Literature Review

The adoption of an agricultural innovation is a process comprised of learning, deciding, and acting over a period of time (Wilkening, 1952). The decision process begins when an individual becomes aware of an innovation's existence and gains some understanding of how it works. The appropriateness of an innovation is determined by both the farmer's socioeconomic conditions, and the technology's characteristics. Once the individual becomes aware of the innovation, he/she implicitly carries out a benefit-cost analysis (economic, social, and cultural) to assess the pros and cons of adoption, given his/her circumstances. If the farmer decides that the benefits of the technology outweigh the costs, the farmer adopts the innovation and continues to use it, if subsequent use confirms his/her initial judgement.

Factors Affecting Adoption

Factors that affect the adoption rates for agricultural innovations have been widely documented. At the individual farmer level, numerous studies have shown that farm size, risk and uncertainty, human capital, labor availability, credit availability, product and factor markets, and tenure affect farmer adoption (Feder, Just and Zilberman, 1985; Schutjer and Van Der Veen, 1976).

Summarizing the adoption literature Coulibaly (1987) identifies two major types of factors that affect farmer adoption of innovations:

- The relative advantage of the innovation
- The characteristics of the adopters

Although presented as discrete categories of factors that influence technology adoption, it is important to keep in mind that there is considerable interdependence both between these major categories, and between factors within each category.

Relative Advantages

The relative advantage of a new technology is defined as its advantage, compared to alternative technologies--including farmers' traditional technologies. Factors that affect relative advantage include the profitability of the innovation, its characteristics, agro-climatic conditions, and the institutional support available to sustain farmer adoption.

Profitability

Higher profitability may be due to improved productivity (lower unit cost), better output quality (e.g., undamaged cowpea seed), or a combination of these.

Norman (1973) found that northern Nigerian farmers allocate their farm resources to maximize profits and food security. Similarly, Sene (1980) found that for Senegalese farmers, profit and food security influenced technology adoption, but that two institutional factors--the organization of production at the farm level and the internal wage system within the household--played a more decisive role in farmer acceptance of new technology. Coulibaly's analysis of the adoption of cowpea technology (high yielding cowpea varieties) in Mali highlights the changes in market opportunity on profitability. Although initially profitable, widespread adoption led to increased production and falling prices, which may make the technology no longer attractive to farmers. Farmers stated that they would "decrease cowpea acreage to supply only their home consumption level if the prices became depressed by the lack of sufficient markets to buy the 1986 production" (Coulibaly, p.77).

Innovation Characteristics

Technologies may be classified in terms of their characteristics. For example, pest protection via resistant varieties require minimal farmers knowledge, compare to insecticide technology. Studies have shown that the specific characteristics of the innovation--such as its compatibility with existing beliefs and farming practices, its technical complexity, and the degree to which it meets a need felt by the adopters--affects the adoption rate.

Agro-climatic Conditions

Agro-climatic conditions influence adoption through their effect on the performance of a technology, and thus its profitability over time (risk). For example, a given technology will perform differently in different soil types, climates, levels of insect infestation, and disease pressures.

Institutional Support

Institutional support is widely recognized as necessary for the adoption of agricultural innovations. The main components of institutional support include access to credit, input and output markets, remunerative product prices, and extension information.

Credit Availability

Farmers facing a cash constraint typically require credit to adopt new technologies. In general, capital markets in Sub-Saharan Africa are poorly developed, and very few formal sector financial institutions serve in rural areas. A study of the adoption of new cowpea varieties around the research station of Cinzana, Mali found that farmer adoption of new varieties and management practices was influenced by the availability of credit for complementary inputs (i.e., insecticide sprayer), as well as access to cowpea marketing outlets (Coulibaly, 1987). Similarly, Chipande (1987) found that in Malawi few female-headed households adopted the recommended agricultural innovation, in part, due to their apparent inability to obtain credit for needed inputs[26].

Input Availability

Agricultural innovations often require timely access to inputs. In developing countries, rural input markets do not always exist or need to be strengthened to make inputs available to farmers when needed (Timmer, et al., 1984).

Output Markets and Prices

Remunerative market prices provide farmers with an incentive to invest in new technology. Yet, due to high transport costs, farm-gate prices (market price minus transport costs) are often significantly below consumer market prices--thereby reducing profitability. Similarly, thin product markets are a major barrier to the adoption of agricultural innovations. In regions where only a small percent of total output is marketed, relatively small increases in output--often due to favorable rainfall--result in large decreases in the market price following harvest.

Extension Access

Because new technology is often knowledge intensive, the quality and level of extension contacts between farmers and extension agencies affects the performance of the technology and the rate of adoption. For example, Falusi (1973) found that in Nigeria, insufficient knowledge about fertilizers reduced farmer adoption of this recommended practice (Falusi as quoted in Coulibaly, p. 22).

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[26]Because of their severe labor constraints and low average cultivated hectarage.

Implications

All of the factors discussed above will affect the profitability of a new technology, and thus, its relative advantage compared to farmers' current technology. Rogers has observed:

> "...the relative advantage of a new idea must be at least 25 to 30 percent higher than existing practice for economic factors to affect peasant's rate of adoption. When an innovation promises only a 5 to 10 percent advantage, the peasant farmers may have difficulty distinguishing its economic advantage" (Rogers as quoted in Schutjer and Van Der Veen, 1976, p. 34).

CIMMYT economists take an even more conservative perspective, arguing that farmers' typically require a minimum return of 50 to 100 percent to adopt a new technology.

Farmer Characteristics

Personal characteristics of farmers that influence to the adoption of innovations include: human capital, farm size, labor availability, and farm income.

Human Capital

Many studies have found a correlation between education and the rate of adoption. Gerhart (1975) in his study of the spread of hybrid maize in Kenya, found formal education was positively (and significantly) correlated with farmer adoption of innovation (Gerhart as cited in Coulibaly, p. 23). Available literature suggests that better educated farmers are earlier adopters and apply modern inputs more efficiently throughout the adoption process (Feder, Just and Zilberman, 1985).

Farm Size

Empirical studies suggest that some modern variable inputs (especially labor-saving technologies) are adopted most rapidly by farmers with large hectarages (Barker and Herdt, 1978). Similarly, evidence from Africa suggests that farmers in a stronger asset position (including access to land) adopted ox plowing to a greater extent than other farmers (Schutjer and Van Der Veen, 1976). In contrast, evidence from Asia suggest that farmers with smaller holdings adopted yield-increasing technologies like modern varieties and insecticide more rapidly than larger land owners (Herdt and Capule, 1983).

Labor Availability

If a technology is labor intensive, the availability of household labor will influence a farmer's adoption decision. For example, Chipande (1987) found that a shortage of labor constrained the adoption of improved maize varieties among female-headed households in Malawi. The labor deficiency of these households made them credit risks because they cannot produce a surplus which can be sold for cash to repay their credit. Similarly, Hicks and Johnson (1974) found that the adoption of labor intensive rice technologies in Taiwan and HYV in India (Harris, 1972) was related to the availability of labor (as cited in Schutjer and Van Der Veen, 1976, p. 25).

Farm Income

Regarding the relationship between farmer income, asset position and willingness to absorb risk and uncertainty, the literature suggest that low income farmers are risk averse. Even if highly profitable "on average", low income farmers cannot risk adopting new technology or management practices which, because of instability of return, threaten the existence of the farmer and his/her household (Schutjer and Van Der Veen, 1976, p. 37). Similarly, Chipande (1987) found that low income was highly associated with very limited adoption of agricultural innovation by female-headed households in Malawi.

4.4 The Model

To analyze the feasibility of farmer adoption of new cowpea storage technologies, the above concepts are incorporated in models with parameters that represent two types of farmer situations--"traditional" (non-adopters) and "advanced farmers. Then, the net benefits are calculated by subtracting the total variable costs from the gross benefit for each alternative technology. Finally, the average and marginal rates of return are calculated. The higher the rate of return, the more likely the farmers will adopt the technology.

4.5 Factors Affecting Cowpea Storage Technology Adoption: Cameroon Situation

Socioeconomic factors which will affect the adoption of new/improved grain storage technologies by cowpea farmers in northern Cameroon include both factors associated to the relative advantage of the innovation(s) and the characteristics of the cowpea farmers.

Relative Advantages

The relative advantage of the new/improved grain storage technologies may be due to factors such as the profitability of the innovation, its characteristics, the agro-climatic conditions, and the institutional support required to sustain the innovations.

Profitability

The new/improved grain storage technologies have the potential to increase farmers' profits by providing better quality (undamaged) cowpea grain for both home consumption and sale. In addition, technologies that reduce losses in essence extend the household supply of grain or make more available for future sales.

Storage Technology Characteristics

Northern Cameroonian cowpea farmers identified storage losses due to pests as a major constraint. Since each of the new/improved cowpea grain storage technologies are technologically simple and relatively easy to use, the analysis assumes that the technology is within the capacity of all types of farmers to adopt.

Management Practices

Cowpea farmers in northern Cameroon follow different management practices (i.e., cowpea variety, cropping system, and insecticide spraying)--which will affect the level of initial[27] insect pest infestation of the cowpea crop and therefore the profitability of adopting new technologies that reduce storage losses.

Insect Damage Over Time

Cowpea farmers in northern Cameroon use various traditional storage techniques (i.e., cloth sacks, granaries, drums)--which affect the current insect damage level on stored cowpea grain. The less protection the traditional storage method provides the farmer the more attractive new technologies that reduce storage losses will be.

Institutional Support

Credit Availability

Cowpea farmers in northern Cameroon both face cash constraints and have very little access to formal credit institutions. This analysis assumes (base run) that cash constrained farmers borrow from informal credit associations (*tontines*) at 3% per month interest rate (based on a conversation with Doyle Baker).

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[27]Analysis of survey data (Wolfson, 1990) showed that for the "non-adopter" farmer, storage losses averaged 15% of the store after 4-6 months in storage. In contrast, for the "moderate" and "advanced adopter" farmer, losses averaged 10% and 7%, respectively.

Input Availability

Some of the new storage technologies require farmers to purchase materials (e.g., plastic sheeting and bags) only available from the Maroua market. Households living close to the market will have better access to these inputs than households living farther away. IRA/CRSP researchers have identified this constraint and are working toward eliminating it by encouraging private merchants to make these materials more readily available.

Market Access and Product Prices

Farmers who live closer to markets will receive a higher farm-gate price (i.e., market price less transport costs) for their cowpea harvest than farmers living farther from the market. This price differential is not incorporated into this analysis explicitly, because of the lack of appropriate data, yet market price will be varied in sensitivity analysis.

The price of cowpea increases from harvest through the storage season. Therefore, farmers who store their crop longer will receive a higher price, than if they had sold their crop at harvest. During normal rainfall years, the market price tends to rise from 101-113 CFA in December-March to a peak of 156-196 CFA in July-August (Figure 5.2).

Economies of Size and Depreciation

Some of the new storage technologies require farmers to purchase materials such as plastic sheeting. Farmers with sufficient cash are likely to purchase the necessary storage materials using their own capital, but those without cash may share these purchased inputs communally. This analysis assumed that for technologies which require purchased materials (i.e., plastic sheeting for solar heater), cowpea farmers will share these inputs between 10 households. Furthermore, the analysis assumes that the solar heater has an expected useful life of 2 years.

Extension Access

Although the technology is relatively simple, farmers with better access to extension will likely incur lower levels of storage losses when using the technology, compared to farmers who have more limited access to extension. The impact of varying access to extension services will be estimated for each treatment by including a loss discount factor.

This analysis assumes that "traditional" and "advanced" farmers using a traditional storage method (the farmer's control) do not require extension service support to achieve current storage loss levels--i.e., loss levels based on analysis of grain samples collected by Wolfson (1990). However, in evaluating the new storage technology, the analysis assumes that "traditional" farmers will obtain only 90% of the gross benefit of the technology and the "advanced" farmer will obtain 100% of the potential benefit.[28]

Farmer Characteristics

Farmer characteristics that may influence the adoption of the proposed new/improved cowpea grain storage technologies include tastes and preferences, farm size, labor availability, farm income and household size.

Tastes and Preferences

Farmers generally prefer undamaged cowpeas (without holes) because of the possible loss in germinative value. Consumers generally prefer undamaged cowpeas

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[28]Advanced adopter farmers tend to grow cotton and are likely to have good extension service (i.e., SODECOTON).

because of the nutritive loss and the "weevily" flavor resulting from the presence of larvae (Murdock, personal interview).

In analyzing the new storage technologies, the market price of the damaged cowpea will be discounted to account for taste preferences for undamaged grain. Although little empirical data exist, antidotal evidence indicate that a premium is paid for undamaged grains. Therefore, undamaged cowpeas will be valued at a 20% higher price than damaged cowpeas.

Farm Size

The majority of cowpea producers in the northern Cameroon grow cowpeas primarily for home consumption, planting on average one hectare (regardless of cropping system) and harvesting 134 kg. Yet since area planted and total production vary between farmer types, these variables are adjusted in the analysis to reflect the total production (i.e., initial quantity placed in on-farm storage) harvested by "traditional" and "advanced" farmers.

Labor Availability

New technologies often increase labor requirements. Farmers may obtain labor by hiring it or by using family labor. If family labor is not available and farmers have cash, they typically hire labor. But, because labor requirements vary little between the new cowpea storage technologies and household labor is assumed to be available, no opportunity cost is assigned to the labor input.

Household Size

By reducing pest losses, the improved storage technology allows households to increase their "supply" of cowpeas. For cowpea deficit households (i.e., available supply is depleted before the next harvest), the new technology allows them to extend their cowpea supply for one or more months. For surplus households, it allows them to sell a larger quantity at the high end-of-season-price. But, assuming that households consume cowpeas (i.e., draw down their stocks) over the storage season, the value of these benefits will vary, depending on the rate of utilization. This analysis assumes household consume 1.6 kgs per capita per month.

4.6 Summary

This analysis generates both the average and marginal rates of return to cowpea grain storage technologies developed and/or promoted by the IRA/CRSP project in northern Cameroon. Differences between farmer "types"[29] with respect to management practices, capacity to bear risk, access to credit and extension services, and access to both input and output markets are considered in the analysis.

Factors which will affect the adoption of the new/improved storage technologies by northern Cameroonian cowpea farmers include both factors associated to the innovation's relative advantage (i.e., the profitability of the innovation, its characteristics, agro-climatic conditions, the institutional support available to sustain farmer adoption) and the characteristics of the farmers (i.e., human capital, farm size, labor availability, farm income, household size). This analysis incorporates these socioeconomic factors to assess, ex ante, the likely profitability of the proposed storage technologies to both "advanced" and "traditional" farmers.

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[29]This analysis assesses the profitability of the various storage technologies under both "advanced" and "traditional" farmers' storage situation.

CHAPTER 5 RATE OF RETURN ANALYSIS OF ALTERNATIVE GRAIN STORAGE TECHNOLOGIES

This chapter is divided into three sections. The first section specifies the cost and benefit streams associated with the technologies evaluated. It describes the components which comprise each stream; the underlaying data, their sources and their limitations; and the assumptions made in interpreting these data. The second section applies average and marginal rate of return analysis to the improved storage technologies under "advanced" and "traditional" farmers' utilization for cowpeas intended for home consumption and/or speculation (sale). It also applies sensitivity analysis to examine the effects of modifying critical parameter values. The final section applies an expected revenue analysis to determine the profitability to an "advanced" farmer investing in either the improved ash storage technology for speculation.

5.1 General Approach

The cost streams represent estimates of material costs and depreciation for the various cowpea grain storage methods. The benefit streams estimate the dollar value of cowpea grain "saved"--calculated as beginning stocks minus consumption, minus loss due to insects, using the traditional and improved cowpea storage technologies.

5.1.1 Storage Technology Cost Stream

<u>Storage Technology--Investment Cost</u>

The first decision a farmer must make is whether to sell his/her crop at harvest or store it in anticipation of a higher future return. Once the farmer has decided to store, he/she must decide which storage method to use. The five alternative storage methods require farmers to invest from 0 to 7,400 CFA (Table 5.1).

Table 5.1 Initial Investment Cost of Various Storage Technologies.

Storage Structure	Container Volume (kg)	Cost/unit[a] (CFA)	Useful Life[b] (yrs)
Cannary	50	1,500	5
Granary	na	na	na
Plastic Bag	50	150	1
Sack	50	300	3
Solar Heater	na	7,400[c]	2

[a]US $1 = 250 CFA.
[b]Although these technologies may have some salvage value, the analyses assumes a zero salvage value.
[c]The cost of the solar heater is shared evenly among 10 households.
Source: Various CRSP Bulletins and key informants.

Interest Payments/Opportunity Cost of Capital

Since formal credit institutions are not available in rural northern Cameroon, cowpea farmers must obtain credit from money lenders, or purchase new technology from their savings. Economic analysis requires that own capital (savings) be valued at its opportunity cost. The base run values capital at 3% per month. This opportunity cost of capital is set at the interest rate that farmers would have to pay if they borrowed from money lenders or informal credit institutions.

Opportunity Cost of Stored Grain

A farmer can either sell his/her cowpea grain at harvest or store it anticipating a higher future price. Yet foregoing the opportunity to sell the grain at harvest may require the low-income farmer to borrow money to cover outstanding debts and immediate household needs. Thus, to evaluate a farmer's "sell at harvest or store" decision, an opportunity cost for the stored grain must be assigned to reflect this foregone cash. The stored grain's opportunity cost is calculated as the farmgate price[30], less the cost of transporting the grain to the market, multiplied by an interest rate (a discount rate)[31]. On the other hand, in evaluating the four storage options (marginal analysis) no opportunity cost is assigned to the stored grain because marginal rate of return analysis requires that only costs that vary between treatments be included in the analysis.

Transportation Cost

Currently, the plastic bags and sheets are only available in the Maroua market and earthenware cannaries and cloth sacks are typically purchases in the Maroua market. To purchase these inputs, farmers would have to pay an average (two way) transportation cost of 500 CFA. But, because this cost does not very across treatments (i.e., one trip would be required to purchase the inputs required for each of the alternative technologies), a transportation cost is not included in the marginal rate of return analysis.

Similarly, no transport cost is included for delivering cowpeas to urban markets, since cost data are not available.

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[30]Since farmgate price data and transport cost are not available, the analysis assumes that the market price equals the farmgate price. This may slightly increase the profitability of the new technology.

[31]This analysis uses a 3% per month interest rate.

Depreciation

An asset with a useful life of greater than 1 year must be amortized over the life of the asset to estimate its annual use cost. Since each technology has a different useful life (Table 5.1), its annual cost is estimated using the formula for calculating straight-line depreciation:

$$D = \frac{(C-S)}{Y} \tag{5.1}$$

where:

D = depreciation per year by straight-line method
C = purchase cost
S = salvage value at end of usage period
Y = expected years of usage

5.1.2 Storage Technology Benefit Stream

Beginning Stock

A household's beginning cowpea stock is equal to last year's carry-over plus the current year's harvest. Since most northern Cameroonian households do not produce sufficient cowpeas to last through the year, beginning stocks are assumed to be equal to the current season's total production.

Dry cowpea pods are generally harvested over a three-month period, beginning in late September and continuing through November. This analysis assumes that the average farmer harvests, drys, and threshes harvested cowpeas during late September through October, and the crop is put into the store on November 1.

Cowpea stock levels are dynamic, constantly changing over time, as a result of draw-down--due to household consumption, market sales, and storage losses. The analysis incorporates this utilization pattern to compute beginning stocks on a monthly basis--each previous month's ending stock becomes the following month's beginning stock.

Consumption

The first component of stock draw-down is total household consumption, which is a function of family size, composition, and the amount eaten per person per meal. Table 5.2 presents the estimated consumption schedule for the traditional and advanced farmers. At current production levels, households produce only enough cowpeas to meet family needs for 4-6 months.

Table 5.2 Estimated Cowpea Consumption Schedule and Months of Self-Sufficiency for Two Farmer Categories, Northern Cameroon.

Household Classification	Household Size	Beginning Stocks (kg)	Consumption /Month (kg)[a]	Harvest Lasts (months)[b]
Traditional	10	82	16	4+
Advanced	19	287	30.4	6+

[a]Estimate based on average consumption of 1.6 kg per person per month.
[b]Months the available stock will last, assuming observed storage losses and zero sales at harvest, as discussed below.
Source: Analysis of data collected by Wolfson (1990).

Storage Losses

The second component of stock draw-down is storage losses, which are determined by the method of storage practiced. Since storage losses represent a cost to the household, investments in technologies that reduce storage losses may be a profitable investment for some households.

Ideally, monthly storage losses associated with each alternative technology should be estimated by monthly sampling of grain stored under each of the storage methods. Since grain samples were only taken once (March, 1990), storage losses over time are estimated using a logistic function[32], where P(t) equals the percentage of storage loss at the time of sampling[33] (Figure 5.1).

$$P_t = \frac{K}{1+be^{-t}} \tag{5.2}$$

where:

P(t) = average total storage loss, in period t
K = loss ceiling, 100% of stock destroyed
b = a parameter of the function
t = time period, life-cycle per generation

Recognizing that storage losses occur throughout the month, average monthly stocks are estimated, based on the mean of beginning and ending stocks.

<u>Sales</u>

The third component of stock draw-down is cowpea grain sales. Since no household level data is available to estimate the volume of cowpea grain sales, the marginal analysis assumes 0% sales at harvest. Subsequent analysis of the farmers' "sell verses store" decision assumes sales at month 10 (August) when the price for cowpea grain peaks (section 5.3).

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[32]Dr. Richard Shade suggested that a logistic function is an appropriate functional form for modeling bruchid population dynamics over time.

[33]Estimates of farmers' storage losses using traditional technology are based on grain samples collected from farmers in March 1990, approximately four months after harvest. Estimates of losses associated with the new storage technology are based on experimental storage trials, sampled after three months in storage.

Output Prices

Cowpea market prices increase from a seasonal low at harvest to a seasonal high preceding the next harvest. If cowpeas are sold, they must be valued at the price households would receive in the month of the sale. But farmers who do not sell cowpeas still benefit from the technology, since reduced storage losses will extend their period of self-sufficiency. For these households, the grain "saved" (as a result of less losses) is valued at the price the household would have to pay to purchase cowpeas in the market at the prevailing market price, if they had not used the storage technology which provided additional months of self-sufficiency.

In 1989 and 1990 the TLU conducted market surveys and reported average monthly prices across six rural markets in the Far North Province[34]. These monthly cowpea market price data are used to value "saved" grain. Average prices, based on two years of price data (1989-90), ranged from a low of 101 CFA/kg in December to a high of 196 CFA/kg in August (Figure 5.2).

These data indicate that the market price varies both between years and over the year. The base run uses an average price across the two markets. A range of prices are later tested during sensitivity analysis to evaluate the impact of cowpea grain prices on the profitability of adoption.

[34]Monthly market prices were collected in six districts of Mayo-Sava and Mayo-Tsanaga Departments.

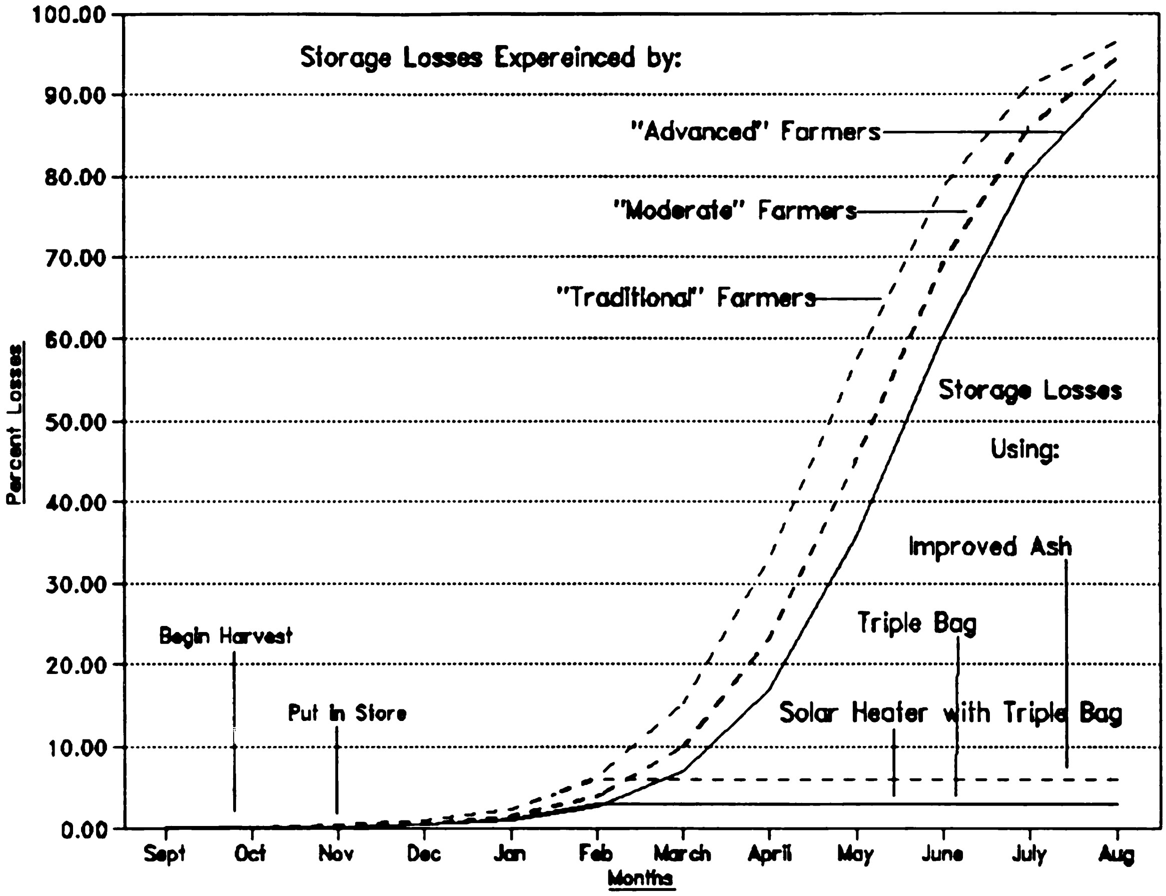

Figure 5.1. Insect Population Growth, On-Farm Trials and Farmers' Samples, Cameroon.

Note: Monthly storage losses are estimated using a log function, in which farmers' losses are based on 4 months of farmer storage and estimates of storage losses under the improved technology are based on 3 months of storage.

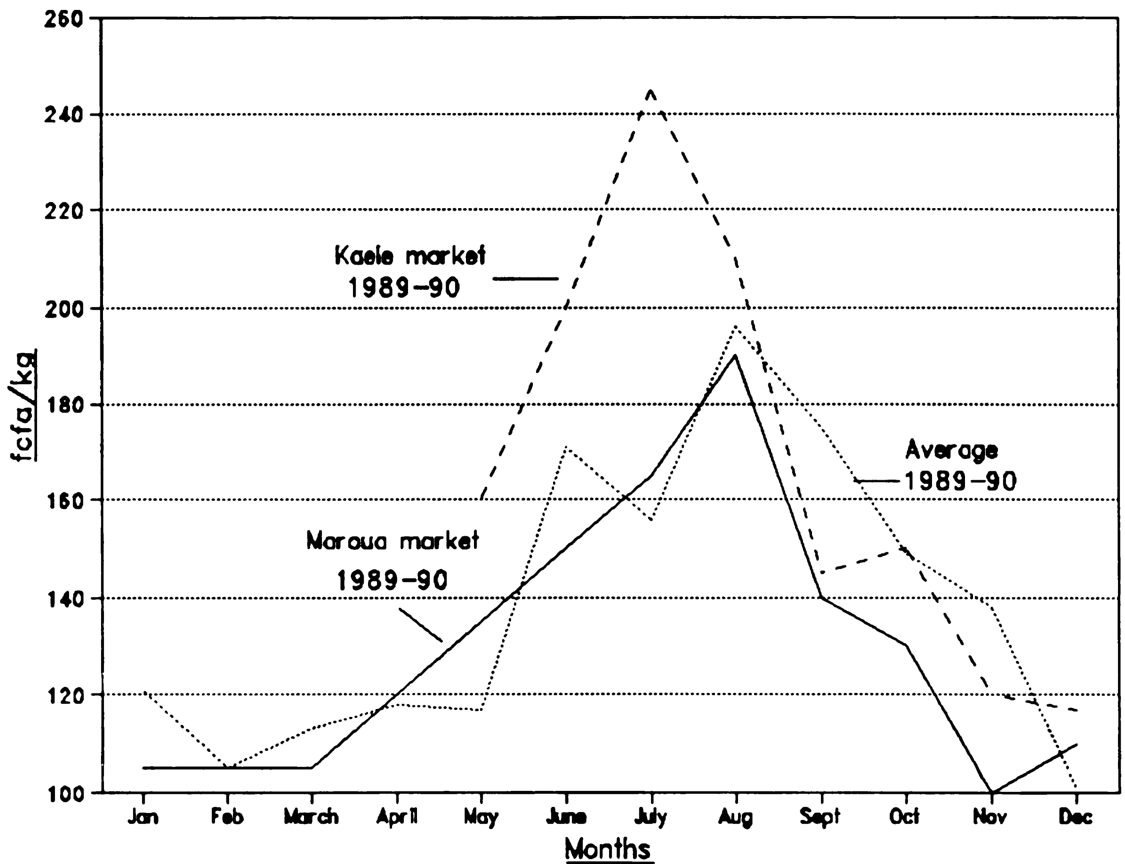

Figure 5.2. Seasonal Cowpea Prices, Far North Province, Cameroon, 1989-1990.

Gross Benefits

Gross benefits to each new cowpea storage technology are estimated by subtracting the storage losses incurred using the new storage technology from the losses incurred under the households' current storage practice to calculate the losses avoided (grain saved) using the new storage technology. The "grain saved" (kg) is then multiplied by the market price in the month in which the household's store is depleted, since in the absence of the new technology the household would have to go to the market to replace the cowpea grain "lost" to storage insect pests.

5.2 Farmers' Utilization of On-Farm Storage

On-farm storage bridges the time lag between production and ultimate use, allowing households to postpone allocative decisions. From the farmers' perspective, by reducing losses, improved on-farm storage technology allows households to: 1) improve their food security by extending their food availability; and 2) provides greater opportunity for speculation (i.e., the ability earn profits by storing and selling when the price is at its peak).

Households' grain-storing decisions are influenced by technical and social factors, including differences in income, production and their consumption patterns. For example, improved storage may allow low-income (and low cowpea production) households to store grain and thereby increase their security in consumption, but the relatively small amount that they produce preclude their storing for speculation. On the other hand, a high-income (and high cowpea production) household may produce sufficient cowpeas to satisfy consumption needs and still have available enough surplus grain for speculation.

As noted earlier, the stock of cowpea grain a farmer has available throughout the storage period is a function of the household's total production (i.e., initial inventory), rate of storage losses, and the rate at which it draws down its stocks. As the household draws down its cowpea inventory, the increasing level of damage caused by storage pests impacts on a decreasing volume of stored grain. Hence, although experiments show high levels of bruchid damage (percent of damaged grain) after several months of storage, these high loss levels actually will only affect farmers who initially placed large grain surpluses in storage. For example, "traditional" farmers with initial cowpea inventories of only 82 kg/household will consume their supply of cowpeas after only four months. Consequently, they have little to gain from adopting improved storage technologies because during the early storage period (months 1-4) bruchid populations remain low. And by the time bruchid damage is potentially severe, these households have depleted their cowpea inventories.

In contrast, "advanced" farmers with initial cowpea inventories of 287 kg/household store sufficient grain to meet household consumption requirements for six months. Thus, these farmers have the most to gain from adopting the improved storage technologies because they still hold substantial inventories during months 5-6 when bruchid populations are high and the potential for severe loss is great.

The following analysis uses benefit-cost analysis to test the hypotheses discussed above by evaluating the economic returns (average and marginal) to adopting the improved storage technology, for both "traditional" and "advanced" farmers[35].

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[35]This analysis focuses on "traditional" and "advanced" farmers because they represent highly contrasting cases. "Traditional" farmers typical of the region, account for 47% of the sample. On the other hand, the analysis of the profitability of new storage technology for "advanced" farmers indicates its potential if new varieties lead to higher yields.

5.2.1 Traditional Farmer Situation

Approximately 47 percent of the survey farmers were classified as "traditional" farmers. These households, categorized as non-adopters of improved production practices, annually harvest an average of 82 kg of cowpea grain and tend to store their cowpea grain in traditional granaries. These households average 10 members, and consume 16 kg/month of cowpea (Table 5.2).

5.2.1.1 Storage for Home Consumption: Base Run

Assuming all of their harvest is stored for home consumption using traditional storage technologies, their inventories will be sufficient to allow the household to meet their consumption requirements for 4 months (November through February) before having to purchase additional cowpeas in the market[36]. By investing in any of the improved cowpea storage technologies developed by CRSP/IRA researchers, the household could extend their period of self-sufficiency. But because "traditional" farmers tend to have less access to extension services and may not use the improved storage technologies correctly, the following analysis assume they capture only 90% of the protection potential of these improved storage technologies.

To assess the likelihood that "traditional" farmers would find these new technologies economically viable (profitable), the average and marginal rates of return to investing in each of the improved cowpea storage technologies were estimated (Table 5.3).

In summary, the base run shows that if a "traditional" farmer values his/her own or borrowed funds at a monthly interest rate of 3% (base run), all of the improved grain

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[36]Based on logistic function estimating weevil population growth under advanced adopter storage conditions.

storage technologies are uneconomical. For all three improved technologies, the value of the "grain saved" is less than the cost of investing in the new technology--resulting in a negative average rate of return to all of these investments. Furthermore, because none of these technologies give positive average rates of return, it is not necessary to estimate their marginal rate of return--all are dominated by (inferior to) the "traditional" farmer's existing storage technology. Farmers will not earn positive profits because the cowpea grain "saved" by adopting these improved storage technologies ranges from only 4.4 to 6.1 kg of grain, depending on the new technology considered. The level of "saved" grain is so low because "traditional" farmers incur minimal grain losses during the first 4 months in storage, while the large potential benefits from improved grain storage technologies do not materialize until later in the storage season--long after these farmers have exhausted their inventories.

5.2.1.2 Storage for Home Consumption: Sensitivity Analysis

To evaluate the sensitivity of these results, with respect to values assigned to the five key parameters[37], each of these values were set at +/- 25 to 50% of their assumed base run values. Recalculation of the average and marginal rates of return showed that only when household storage losses were increased by 50%, did the improved ash and triple bag technology have a positive rate of return of 30 and 5.1%, respectively. For every other run in the sensitivity analysis, the improved grain storage technologies remained dominated by the "traditional" farmers' existing storage method (Tables 5.4 - 5.6).

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[37]The five parameters varied in the sensitivity analysis are the households' current level of grain losses using his/her traditional storage method, grain losses associated with the improved storage technologies, cost of the technology, market price of cowpea grain, and the opportunity cost of capital.

Table 5.3 Base Run for "Traditional" Farmers: Partial Budget and Rate of Returns Analysis of Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a].

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved (kgs)	0	4.4	6.1	6.1
Partial Budget (CFA)				
Gross Benefits[f]	0	497	689	689
Total Costs[g]	0	3,478	1,043	1,901
Annual Costs[h]	0	696	1,043	1,472
Net Benefits (gross benefits minus annual cost)	NA	-199	-354	-783
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	-199	-155	-429
Additional Annual Costs	NA	696	647	429
Rate of Returns (%)				
Average	NA	-29	-34	-53
Marginal	NA	D	D	D

[a]82 kg of cowpea grain put into storage.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[g]Includes opportunity cost of capital (3% per month) for 5 months (Nov. - March).
[h]Total costs/useful life of technology.
NA = not applicable; D = dominated.

Table 5.4 Sensitivity Analysis: "Traditional" Farmer Using **Improved Ash Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5
Losses using farmers' technology (kg)[a]	7.8	b[b] +/- 50%	b	b	b	b
Losses using improved ash technology (kg)[c]	3.4	b	b +/- 50%	b	b	b
Cost of improved ash technology per unit (CFA)	696	b	b	b +/- 25%	b	b
Market price of cowpea grain (CFA)	113	b	b	b	b +/- 25%	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%
ARR (%) for:	-29					
· decrease in value of variable		-91.1	-14.9	-4.8	-46.4	-23.1
· increase in value of variable		+30.0	-43.8	-42.8	-10.6	-33.6
Change[d] in ARR from base run, due to:						
· decrease in value of variable		-62.1	+14.1	+24.2	-17.4	+5.9
· increase in value of variable		+59	-14.8	-13.8	+18.4	-4.6
MRR (%) for:	D[e]					
· decrease in value of variable		D	D	D	D	D
· increase in value of variable		30	D	D	D	D
Change[d] in MRR from base run, due to:						
· decrease in value of variable		D	D	D	D	D
· increase in value of variable		+30	D	D	D	D

[a]Loss when storing 82 kg intended for home consumption in a granary.
[b]"b" represents base run values for the variable.
[c]Storage of 82 kg intended for home consumption using improved ash storage technology.
[d]Absolute percentage points.
[e]"D" represents a dominated treatment.
Note: See Appendix Tables A1 - A5 for calculations supporting these results.

Table 5.5 Sensitivity Analysis: "Traditional" Farmer Using **Triple Bag Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5
Losses using farmers' technology (kg)[a]	7.8	b[b] +/- 50%	b	b	b	b
Losses using triple bag technology (kg)[c]	1.7	b	b +/- 50%	b	b	b
Cost of triple bag technology per unit (CFA)	1,043	b	b	b +/- 25%	b	b
Market price of cowpea grain (CFA)	113	b	b	b	b +/- 25%	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%
ARR (%) for:	-34					
• <u>decrease</u> in value of variable		-76.1	-29.4	-12.0	-50.4	-29.0
• <u>increase</u> in value of variable		+5.1	-39.1	-47.2	-17.4	-39.5
Change[d] in ARR from base run, due to:						
• <u>decrease</u> in value of variable		-42.1	+4.6	+22.0	-16.4	+5.0
• <u>increase</u> in value of variable		+39.1	-5.1	-13.2	+16.6	-5.5
MRR (%) for:	D[e]					
• <u>decrease</u> in value of variable		D	D	D	D	D
• <u>increase</u> in value of variable		D	D	D	D	D
Change[d] in MRR from base run, due to:						
• <u>decrease</u> in value of variable		D	D	D	D	D
• <u>increase</u> in value of variable		D	D	D	D	D

[a]Storage loss when storing 82 kg intended for home consumption in a granary.
[b]"b" represents base run values for the variable.
[c]Storage of 82 kg intended for home consumption using triple bag storage technology.
[d]Absolute percentage points.
[e]"D" represents a dominated treatment.
Note: See Appendix Tables A1 - A5 for calculations supporting these results.

Table 5.6 Sensitivity Analysis: "Traditional" Farmer Using **Solar Heater with Triple Bagging Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5
Losses using farmers' technology (kg)[a]	7.8	b[b] +/- 50%	b	b	b	b
Losses using solar heater with triple bag technology (kg)[c]	1.7	b	b +/- 50%	b	b	b
Cost of solar heater with triple bag technology per unit (CFA)	1,472	b	b	b +/- 25%	b	b
Market price of cowpea (CFA)	113	b	b	b	b +/- 25%	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%
ARR (%) for:	-53					
• <u>decrease</u> in value of variable		-83.1	-50.0	-37.6	-64.9	-49.6
• <u>increase</u> in value of variable		-25.5	-56.9	-62.6	-41.4	-56.5
Change[d] in ARR from base run, due to:						
• <u>decrease</u> in value of variable		-30.1	+3.0	+15.4	-11.9	+3.4
• <u>increase</u> in value of variable		+27.5	-3.9	-9.6	+11.6	-3.5
MRR (%) for:	D[e]					
• <u>decrease</u> in value of variable		D	D	D	D	D
• <u>increase</u> in value of variable		D	D	D	D	D
Change[d] in MRR from base run, due to:						
• <u>decrease</u> in value of variable		D	D	D	D	D
• <u>increase</u> in value of variable		D	D	D	D	D

[a]Storage of 82 kg intended for home consumption in a granary.
[b]"b" represents base run values for the variable.
[c]Storage of 82 kg intended for home consumption using solar heater with triple bag storage technology.
[d]Absolute percentage points.
[d]"D" represents a dominated treatment.
Note: See Appendix Tables A1 - A5 for calculations supporting these results.

5.2.2 Advanced Farmer Situation

Approximately 22 percent of the survey farmers were classified as "advanced" farmers. These households adopted the improved production technology package, annually harvested 287 kg of cowpea grain and tended to store their grain in cloth sacks. These households average 19 members and consumed 30.4 kg/month of cowpeas (Table 5.2).

5.2.2.1 Storage for Home Consumption: Base Run

Assuming all of their harvest is stored for home consumption using "advanced" farmers' storage technology, their inventories would be sufficient to allow the household to meet their consumption requirements for approximately 6.5 months (November through mid-May) before having to purchase additional cowpeas in the market. By investing in the improved cowpea storage technology, the household could extend their period of self-sufficiency.

Because "advanced" farmers tend to have good access to extension services, the following analysis assumes they will use the improved storage technologies correctly and receive all (100%) potential benefits.

When an "advanced" farmer uses the improved storage technologies, he/she will be able to extend their period of self-sufficiency approximately two more months (mid-May through mid-July) (Table 5.7).

To assess the likelihood that "advanced" farmers would find these new technologies economically viable (profitable), the average and marginal rate of return to investing in each of the improved cowpea storage technologies were calculated (Table 5.7).

These results show that when an "advanced" farmer values his/her own funds or borrows the funds at a monthly interest rate of 3% (base run), adopting the improved ash, triple bag, and solar heater with triple bag storage technology implies a 177, 116, and 90% average rate of return (ARR), respectively to grain stored for home consumption. These results suggest that adopting any one of the alternative improved/new grain storage technologies would by economically attractive for the "advanced" farmer, since all exceed the 50% minimum rate of return proposed by CIMMYT (1988).

Marginal returns analysis provides a technique for looking more critically at the "advanced" farmers' choice of technology decision. Table 5.7 presents data for the alternative improved technologies, arranged from the least costly (improved ash) to the most expensive (solar heater with triple bag). Compared to the farmers' current storage technology, improved ash gives a marginal ROR of 265% In other words, by investing an additional 1,476 CFA in ash storage, benefits are increased to 3,917 CFA. Thus, the marginal ROR (3,917 divided by 1,467) equals 265%--suggesting a very attractive investment option.

In order to adopt triple bagging, the farmer would have to invest an additional 1,107 CFA (above the cost of the ash technology) but, he/she would earn -66 CFA less profit (net benefits) from investing in the triple bag technology--compared to ash storage. Similarly, although the solar heater with triple bag technology has a positive (90%) ARR, it generates a lower net benefit (-455 CFA)--compared to the triple bag technology.

In summary, the base run analysis shows that for an "advanced" farmer storing his/her total crop for home consumption, all three improved technologies give attractive

ARRs. But, the MRR analysis clearly shows that if a farmer could adopt improved ash storage, it would be irrational for him/her to invest in either the triple bag or solar heater with triple bag technology--since they are all dominated by improved ash storage. These results are largely driven by the storage loss data used in the analysis. Available experimental data (Table 3.5) show that--in terms of potential pest loss reduction--the triple bag technology is only slightly more effective than improved ash storage. Furthermore, the triple bag technology and solar heater with triple bagging are equivalent--in terms of loss reduction--but the later is more costly to adopt.

5.2.2.2 Storage for Home Consumption: Sensitivity Analysis

Although the base run represents the "best estimate" of the average and marginal returns to cowpea grain storage technologies, sensitivity analysis is conducted to test the variability in rate of return, associated with alternative assumptions regarding the data values used in these analyses. Further, given that some data used in the analysis are based on "informed assumptions" rather than empirical findings, sensitivity analysis indicated the degree to which each assumption affects the results.

Five parameters[38] were identified as having a significant influence on the rates of return for the improved grain storage technologies (Tables 5.8 - 5.10). Six sensitivity analyses are presented below. Each analysis assesses the impact of altering one of the five "critical parameters" on the rate of return to investing in the three new technologies--improved ash storage, triple bagging storage, and solar heater with triple bag storage.

[38]The five parameters varied in the sensitivity analysis are the households' current level of grain losses using his/her traditional storage method, the losses associated with using the improved technologies, technology cost, market price of cowpea grain, and the opportunity cost of capital.

Table 5.7 Base Run for "Advanced" Farmers: Partial Budget and Rate of Returns Analysis of Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a].

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved (kgs)	0	52.4	61.3	61.3
Partial Budget (CFA)				
Gross Benefits[f]	0	6,131	7,172	7,172
Total Costs[g]	2,214	11,069	3,321	4,231
Annual Costs[h]	738	2,214	3,321	3,776
Net Benefits (gross benefits minus annual costs)	NA	3,917	3,851	3,396
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	3,917	-66	-455
Additional Annual Costs	NA	1,476	1,107	455
Rate of Returns (%)				
Average	NA	177	116	90
Marginal	NA	265	D	D

[a]287 kg of cowpea grain put into storage.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[g]Includes opportunity cost of capital (3% per month) for 7 months (November - May).
[h]Total costs/useful life of technology.
NA = not applicable; D = dominated.

Table 5.8 Sensitivity Analysis: "Advanced" Farmer Using **Improved Ash Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5
Losses using farmer's technology (kg)[a]	70.4	b[b] +/- 50%	b	b	b	b
Losses using improved ash technology (kg)[c]	18.0	b	b +/- 50%	b	b	b
Cost of improved ash technology per unit (CFA)	2,214	b	b	b +/- 25%	b	b
Market price of cowpea grain (CFA)	117	b	b	b	b +/- 25%	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%
ARR (%) for:	177					
• decrease in value of variable		236	196	269	108	207
• increase in value of variable		268	157	122	246	150
Change[d] in ARR from base run, due to:						
• decrease in value of variable		+59	+19	+92	-69	+30
• increase in value of variable		+91	-20	-55	+69	-27
MRR (%) for:	265					
• decrease in value of variable		354	294	404	162	310
• increase in value of variable		403	235	182	369	225
Change[d] in MRR from base run, due to:						
• decrease in value of variable		+89	+29	+139	-103	+45
• increase in value of variable		+138	-30	-83	+104	-40

[a]Storage losses when storing 287 kg intended for home consumption in a cloth sack.
[b]"b" represents base run values for the variable.
[c]Storage of 287 kg intended for home consumption using improved ash storage technology.
[d]Absolute percentage points.
Note: See Appendix Tables A6 - A11 for calculations supporting these results.

Table 5.9 Sensitivity Analysis: "Advanced" Farmer Using **Triple Bag Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5
Losses using farmer's technology (kg)[a]	70.4	b[b] +/- 50%	b	b	b	b
Losses using triple bag technology (kg)[c]	9.1	b	b +/- 50%	b	b	b
Cost of triple bag technology per unit (CFA)	3,321	b	b	b +/- 25%	b	b
Market price of cowpea grain (CFA)	117	b	b	b	b +/- 25%	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%
ARR (%) for:	116					
• <u>decrease</u> in value of variable		169	123	188	62	139
• <u>increase</u> in value of variable		177	74	73	170	95
Change[d] in ARR from base run, due to:						
• <u>decrease</u> in value of variable		+53	+7	+72	-54	+23
• <u>increase</u> in value of variable		+61	-42	-43	+54	-21
MRR (%) for:	D[e]					
• <u>decrease</u> in value of variable		35	D	25	D	4.2
• <u>increase</u> in value of variable		D	D	D	18	D
Change[d] in MRR from base run, due to:						
• <u>decrease</u> in value of variable		+35	D	+25	D	+4.2
• <u>increase</u> in value of variable		D	D	D	+18	D

[a]Storage of 287 kg intended for home consumption in cloth sacks.
[b]"b" represents base run values for the variable.
[c]Storage of 287 kg intended for home consumption using triple bag storage technology.
[d]Absolute percentage value.
[e]"D" represents a dominated treatment.
Note: See Appendix Tables A6 - A11 for calculations supporting these results.

Table 5.10 Sensitivity Analysis: "Advanced" Farmer Using Solar Heater with Triple Bagging Storage Technology, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Losses using farmer's technology (kg)[a]	70.4	b[b] +/- 50%	b	b	b	b	b
Losses using solar heater with triple bag technology (kg)[c]	9.1	b	b +/- 50%	b	b	b	0
Cost of solar heater with triple bag technology per unit (CFA)	3,776	b	b	b +/- 25%	b	b	b
Market price of cowpea (CFA)	117	b	b	b	b +/- 25%	b	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%	b
ARR (%) for:	90						
• <u>decrease</u> in value of variable		137	96	153	42	111	146
• <u>increase</u> in value of variable		144	53	-27	137	72	
Change[d] in ARR from:							
• <u>decrease</u> in value of variable		+47	+6	+63	-52	+21	+56
• <u>increase</u> in value of variable		+54	-37	-63	+47	-18	
MRR (%) for:	D[e]						
• <u>decrease</u> in value of variable		D	D	D	D	D	35
• <u>increase</u> in value of variable		D	D	D	D	D	
Change[d] in MRR from:							
• <u>decrease</u> in value of variable		D	D	D	D	D	+35
• <u>increase</u> in value of variable		D	D	D	D	D	

[a]Storage of 287 kg intended for home consumption in cloth sacks.
[b]"b" represents economic base run values for the variable.
[c]Storage of 287 kg intended for home consumption using solar heater with triple bag storage technology.
[d]Absolute percentage points.
[e]"D" represents a dominated treatment.
Note: See Appendix Tables A6 - A11 for calculations supporting these results.

Run 1: Farmers' Current Level of Storage Losses

In the base run analysis, annual storage losses were estimated using a logistic function (Equation 5.1), based on farm-level storage loss data collected in March 1990. By testing the robustness of these estimates, sensitivity analysis determines to what degree the rate of return estimate depends on the accuracy of these data.

Improved Ash Storage

In the base run analysis, by adopting improved ash storage "advanced" farmers gained an additional 52.4 kg of cowpea grain; and earned a 177 percent ARR and a 265 percent MRR on their investment (Table 5.7). When the assumed level of the "advanced" farmers' current storage losses is increased by 50%, (10.5% of the stock lost by the end of the fourth month in storage[39] vs. 7% in the base run), the additional grain available increases to 69.7 kg; and the ARR and MRR increase to 368 and 403 percent, respectively. This is because when the assumed level of farmers' losses is increased by 50%, the household runs out of cowpeas approximately 2 weeks sooner. By adopting improved ash storage, the household saves 69.7 kg (vs. 52.4 kg in the base run). These "saved" cowpeas are valued at the May market price of 117 CFA/kg, since this is the price the household would have had to pay to purchase cowpeas in the market in May--if they had not adopted ash storage.

In contrast, when the assumed level of the "advanced" farmers losses is decreased by 50% (3.5% of the stock lost by the fourth month in storage vs. 7% in the base run), adopting ash storage reduces the amount of grain saved to 44.8 kg; and the ARR and MRR to ash storage increase to 239 and 354 percent, respectively. Intuitively, one would

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[39]Survey data showed that losses averaged 7% by the end of four months in storage. In this analysis, this loss parameter was increased/decreased 50% and the new value was used in the logistic curve to estimate total losses.

expect that the returns to improved grain storage technologies should decrease when the level of protection under the farmers' current storage method increases. This observed counter intuitive increase in returns to adopting ash storage occurs for the following reason. If farmers' losses are 50% less using their current technology, they are able to meet consumption requirements from their own stocks for 7 months and two weeks (compared to 6.5 months in the base run)--lessening the benefits of improved storage technologies. But, the additional grain saved (44.8 kg) by adopting improved ash storage under this situation is valued at the June market price of 171 CFA/kg, since this is the price the household would have had to pay to purchase cowpeas in the market in June. Consequently, the net benefit to adopting the improved ash storage technology increases because of the rise in the market price of cowpea grain (from 117 CFA/kg in May to 171 CFA/kg in June).

Triple Bag Storage

In the base run, by adopting triple bag storage "advanced" framers gained an additional 61.3 kg and; earned a 116 percent ARR, but the MRR was dominated by improved ash storage (i.e., the return to the additional capital required to invest in triple bag storage was less than the additional cost of this investment[39]) (Table 5.7). When the assumed level of the "advanced" farmers' current storage losses is increased by 50%, the ARR increases 61 percentage points to 177, but the MRR remains dominated. The ARR increases because when assumed farmers' losses were increased by 50%, the household runs out of cowpeas sooner in May, when the market cowpea price is 117 CFA/kg. Now adoption of triple bagging "saves" 78.7 kg (vs. 61.3 kg in the base run) of cowpeas, which is valued at 117 CFA/kg. But, the MRR is still dominated because the benefits (i.e., reduced losses) of the triple bag storage are not sufficient to cover the additional costs of the triple bag technology.

In contrast, when the assumed level of "advanced" farmers' losses is decreased by 50%, the additional grain made available by adopting triple bagging decreases to 53.8 kg; and the ARR to triple bagging increases by 53 percentage points to 169 percent and the MRR increases to 35%. The household under the current storage method now runs out of cowpeas in June, when the market price is 171 CFA/kg. Even though the amount of cowpea grain "saved" decreases to 53.8 kg, the "saved" grain is valued at a higher price--causing the ARR and MRR to increase.

Solar Heater with Triple Bag Storage

In the base run, by adopting the solar heater with triple bagging storage "advanced" farmers gained an additional 61.3 kg[40]; and earned a 90% ARR, but the MRR was dominated by ash storage (Table 5.7). When the assumed level of the "advanced" farmers' current storage loss estimate is increased by 50%, the ARR increases 54 percentage points to 144 percent. The ARR increases because when the assumed level of farmers' losses is increased by 50%, the household runs out of cowpeas sooner in May, when the market cowpea price is 117 CFA/kg. Now, adoption of the solar heater with triple bagging "saves" 78.7 kg (vs. 61.3 kg in the base run) of cowpeas, which is valued at 117 CFA/kg. But, the MRR is still dominated because the benefits (i.e., reduced losses) of the solar heater with triple bag storage are not sufficient to cover the additional costs of the solar heater with triple bag technology.

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[40]The experimental results showed that triple bagging and the solar heater with triple bagging were equally effective in reducing storage losses.

In contrast, when the assumed level of "advanced" farmers' losses are decreased by 50%, the ARR to solar heater with triple bagging increases by 47 percentage points to 137 percent and the MRR remains dominated. The household now runs out of cowpeas in June, when the market price is 171 CFA/kg. Even though the amount of cowpea grain "saved" decreases to 53.8 kg, the "saved" grain is valued at a higher price--causing the ARR to increase.

Run 2: Improved Storage Technology Protection

In the base run analysis, the level of protection data were based on on-farm demonstrations of the improved storage technologies. Because so few trials were conducted, the sensitivity of the returns in the base run is tested by assuming various levels of protection provided by the three improved technologies.

Improved Ash Storage

When the assumed level of loss using improved ash storage is increased (i.e., less effective) by 50% (9% of the stock lost by the third month in storage vs. 6% in the base run), the ARR decreases by 20 percentage points to 157 percent and the MRR decreases by 30 percentage points to 235 percent. This observed decrease in returns to adopting ash storage occurs because assuming 50% more "losses" under the improved ash technology results in less grain "saved" (48.6 kg), which is valued at the May market price of 117 CFA/kg. Since the traditional storage practice (cloth sacks) is being replaced by the improved ash storage, an increase in the value of this parameter will result in a lower rate of return. By setting a lower protection level for the improved ash storage technology, the improved ash storage technology will certainly appear less profitable than in the base run.

When the assumed level of loss using the improved ash storage is decreased (i.e., more effective) by 50% (3% of the stock lost by the third month in storage vs. 6 % in the base run), the ARR increases by 19 percentage points to 196 percent, and the MRR increases by 29 percentage points to 294 percent. Setting a higher protection level for the improved ash storage technology, results in more grain "saved" (56.04 kg), which is valued at the May market price of 117 CFA/kg.

Triple Bag Storage

When the assumed level of loss using triple bag storage is increased (i.e., less effective) by 50% (4.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR decreases by 42 percentage points to 74 percent and the MRR remains dominated. Setting a 50% lower protection level for triple bagging, results in less grain "saved" (49.5 kg), and in turn a lower rate of return.

When the assumed level of loss using triple bag storage is decreased (i.e., more effective) by 50% (1.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR increases by 7 percentage points to 123 percent and the MRR remains dominated. Setting a 50% higher protection level for triple bagging, results in more grain "saved" (63.2 kg), and in turn a higher rate of return.

Solar Heater with Triple Bag Storage

When the assumed level of loss using the solar heater with triple bag storage is increased (i.e., less effective) by 50% (4.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR decreases by 37 percentage points to 53 percent and the MRR remains dominated. Setting a 50% lower protection level for the solar heater with triple bagging technology, results in less grain "saved" (49.5 kg), and in turn a lower rate of return.

When the assumed level of loss using the solar heater with triple bag storage is decreased (i.e., more effective) by 50% (1.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR increases by 6 percentage points to 96 percent and the MRR remains dominated. Setting a 50% higher protection level for the solar heater with triple bagging technology, results in more grain "saved" (63.2 kg), and in turn a higher rate of return.

Run 3: Improved Storage Technology Cost

In the base run analysis, although most cost figures of the improved storage technology were directly quoted from CRSP documents, there is still a possibility that variable costs were over/under estimated. Thus, the cost variable is varied to estimate how sensitive the returns to improved grain storage technologies are to higher/lower total input costs.

Improved Ash Storage

When total input costs of the improved ash storage technology are increased by 25%, the ARR decreases by 55 percentage points to 122 percent and the MRR decreases by 83 percentage points to 182 percent. This observed decrease in the rates of return to improved ash are expected because although the benefits (52.4 kg of grain "saved") have not changed, the cost of adopting the improved ash storage technology is now 25% higher.

When total input costs of the improved ash storage technology are decreased by 25%, the ARR increases by 92 percentage points to 269 percent and the MRR increases by 139 percentage points to 404 percent. This observed increase in the rates of return to improved ash is again expected because although the benefits (52.4 kg of grain "saved") have not changed, the cost of adopting the improved ash storage technology is now 25% lower.

Triple Bag Storage

When total input costs of the triple bag storage technology are increased by 25%, the ARR decreases by 43 percentage points to 73 percent and the MRR remains dominated. This observed decrease in the ARR to triple bagging is expected because although the benefits (61.3 kg of grain "saved") have not changed, the cost of adopting the triple bag storage technology is now 25% higher.

When total input costs of the triple bag storage technology is decreased by 25%, the ARR increases by 72 percentage points to 188 percent and the MRR increases by 25 percentage points to 25 percent. This observed increase in the ARR to triple bagging is again expected because although the benefits (61.3 kg of grain "saved") have not changed, the cost of adopting the triple bag storage technology is now 25% lower. The MRR increases because the return to the additional capital required to invest in triple bag storage is now greater than the additional cost of this investment.

Solar Heater with Triple Bag Storage

When total input costs of the solar heater with triple bag storage technology are increased by 25%, the ARR decreases by 63 percentage points to -27 percent and the MRR remains dominated. The ARR to the solar heater with triple bagging becomes negative because although the benefits (61.3 kg of grain "saved") have not changed, the cost of adopting the solar heater with triple bag storage technology is now 25% higher.

When total input costs of the solar heater with triple bag storage technology is decreased by 25%, the ARR increases by 63 percentage points to 153 percent and the MRR remains dominated. This observed increase in the ARR is again expected because although the benefits (61.3 kg of grain "saved") have not changed, the cost of adopting the triple bag storage technology is now 25% lower.

<u>Run 4: Market Price of Cowpea</u>

In the base run analysis, the market price for cowpea grain was based on two years of price data (1989-1990) collected by the TLU. Because market prices vary across years and across markets, the grain price is varied to estimate how sensitive the returns to improved grain storage technologies are to price.

Improved Ash Storage

When the market price for cowpea grain is increased by 25% (from 117 to 146.25 CFA/kg), the ARR increases by 69 percentage points to 246 percent and the MRR increases by 104 percentage points to 369 percent. This observed increase in the rates of return to improved ash is expected because the value of the benefits (52.4 kg of grain "saved") has increased, but the cost of adopting the improved ash storage technology has not changed.

When the market price for cowpea grain is decreased by 25% (from 117 to 87.75 CFA/kg), the ARR decreases by 69 percentage points to 108 percent and the MRR decreases by 103 percentage points to 162 percent. This observed decrease in the rates of return to improved ash is again expected because the value of the benefits (52.4 kg of grain "saved") has decreased, but the cost of adopting the improved ash storage technology has not changed.

Triple Bag Storage

When the market price for cowpea grain is increased by 25%, the ARR increases by 54 percentage points to 170 percent and the MRR increases by 18 percentage points to 18 percent. This observed increase in the rates of return to triple bagging is expected because the value of the benefits (61.3 kg of grain "saved") have increased, but the cost of adopting the triple bag storage technology has not changed.

When the market price for cowpea grain is decreased by 25%, the ARR decreases by 54 percentage points to 62 percent and the MRR remains dominated. This observed decrease in the rates of return to triple bagging is again expected because the value of the benefits (61.3 kg of grain "saved") have increased, but the cost of adopting the triple bagging storage technology has not changed.

Solar Heater with Triple Bag Storage

When the market price for cowpea grain is increased by 25%, the ARR increases by 47 percentage points to 137 percent and the MRR remains dominated. This observed increase in the rate of return to the solar heater with triple bagging is expected because the value of the benefits (61.3 kg of grain "saved") has increased, but the cost of adopting the solar heater with triple bag storage technology has not changed.

When the market price for cowpea grain is decreased by 25%, the ARR decreases by 52 percentage points to 42 percent and the MRR remains dominated. This observed decrease in the rate of return to the solar heater with triple bagging is again expected because the value of the benefits (61.3 kg of grain "saved") has increased, but the cost of adopting the solar heater with triple bagging storage technology has not changed.

<u>Run 5: Interest Rate/Opportunity Cost of Capital</u>

In the base run analysis, the opportunity cost of capital is set at a 3 percent per month interest rate, representing the interest rate that farmers would have to pay if they borrowed from money lenders or informal credit institutions. The opportunity cost of capital represents an additional cost to the farmer of adopting any of the improved storage technologies and thus affects the returns to the improved technologies.

Improved Ash Storage

When the monthly interest rate for capital invested in improved ash storage is increased by 50% (4.5% vs. 3% in the base run), the ARR decreases by 27 percentage points to 150% and the MRR decreases by 40 percentage points to 225%. This observed decrease in the rates of return to improved ash results from an increase in the cost of adopting the improved ash storage, while the benefits (52.4 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in improved ash storage is decreased by 50% (1.5% vs. 3% in the base run), the ARR increases by 30 percentage points to 207% and the MRR increases by 45 percentage points to 310%. This observed increase in the rates of return to improved ash is expected because the benefits (52.4 kg of grain "saved") have not changed, but the cost of adopting the improved ash storage technology has decreased.

Triple Bag Storage

When the monthly interest rate for capital invested in triple bag storage is increased by 50%, the ARR decreases by 21 percentage points to 95% and the MRR remains dominated. This observed decrease in the rate of return to triple bagging results from an increase in the cost of triple bag storage, while the benefits (61.3 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in triple bag storage is decreased by 50%, the ARR increases by 23 percentage points to 139% and the MRR increases by 4.2 percentage points to 4.2%. This observed increase in the rates of return to triple bag storage is expected because the benefits (61.3 kg of grain "saved") have not changed, but the cost of adopting the triple bag storage technology has decreased.

Solar Heater with Triple Bag Storage

When the monthly interest rate for capital invested in the solar heater with triple bagging storage is increased by 50%, the ARR decreases by 18 percentage points to 72% and the MRR remains dominated. This observed decrease in the ARR to the solar heater with triple bag storage results from an increase in the cost of adopting the technology, while the benefits (61.3 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in the solar heater with triple bagging storage is decreased by 50%, the ARR increases by 21 percentage points to 111% and the MRR remains dominated. This observed increase in the ARR to the solar heater with triple bag storage results because the benefits (61.3 kg of grain "saved") have not changed, but the cost of adopting the solar heater with triple bag storage technology has decreased.

Run 6: Solar Heater with Triple Bag Technology Provides 100% Protection

In the base run analysis, the protection level provided by the solar heater with triple bagging storage technology was set equal to the triple bagging storage technology because on-farm demonstration trials of the improved storage technologies showed that the two technologies were equally effective (Table 3.5). Intuitively one would expect that losses would be lower for grain protected by the solar heater with triple bag technology compared to triple bagging alone, because the solar heater kills all bruchids before the grain is put into plastic bags. Laboratory experimental results/data suggest that the solar heater with triple bagging storage technology provides 100% protection[41]. Run 6 analyses the profitability of the solar heater with triple bagging technology, under the assumption of 100% protection. Since this assumption only affects the profitability of the solar heater with triple bag technology, Run 6 applies to only this technology (Table 5.10).

Solar Heater with Triple Bag Storage

When the solar heater with triple bag technology protection is assumed to be 100%, the ARR to the solar heater with triple bag storage increases 56 percentage points to 146% and the MRR (relative to triple bagging) increases 35 percentage points to 35%.

5.2.2.3 Storage for Home Consumption: Summary

Benefit Parameters

The sensitivity analysis shows that for an "advanced" farmer storing his/her total crop for home consumption, the rates of return to the improved ash, and to a lesser extent, triple bagging storage technologies are most affected by the assumed level of losses using farmers' current storage technology. When the assumed level of farmers' losses was increased from 7 to 10.5%, the improved ash technology gave an ARR (MRR) of 268% (403%), compared to 177% (265%) in the base run. When the assumed level of farmers' losses was increased from 7 to 10.5%, the triple bagging technology gave an ARR (MRR) of 177% (dominated), compared to 116% (dominated) in the base run. On the other hand, the when the assumed level of farmers' losses was decreased from 7 to 3.5%, the improved ash technology gave an ARR (MRR) of 236%

[41]A portion of the "losses" observed in the on-farm demonstration/trial were likely caused by bruchids during the post-harvest period, prior to heating and placing the grain in triple bags.

(354%), compared to 177% (265%) in the base run. When the assumed level of farmers' losses was decreased from 7 to 3.5%, the triple bagging technology gave an ARR (MRR) of 169% (35%), compared to 116% (dominated) in the base run.

Similarly, relatively small changes (+/- 25%) in cowpea grain price resulted in relatively large differences in their profitability. When the market price of cowpea grain increased from 117 to 146.25 CFA/kg, the improved ash technology gave an ARR (MRR) of 246% (369%), compared to 177% (265%) in the base run. When the market price of cowpea grain increased from 117 to 146.25 CFA/kg, the triple bagging technology gave an ARR (MRR) of 170% (18%), compared to 116% (dominated) in the base run. On the other hand, when the market price of cowpea grain decreased from 117 to 87.75 CFA/kg, the improved ash technology gave an ARR (MRR) of 108% (162%), compared to 177% (265%) in the base run. When the market price of cowpea grain decreased from 117 to 87.75 CFA/kg, the triple bagging technology gave an ARR (MRR) of 62% (dominated), compared to 116% (dominated) in the base run.

Interestingly, the efficacy of the improved storage technologies affects their profitability to a lesser extent than other factors. Only the profitability of the improved ash technology is affected by variations in the assumed/estimated level of protection. Both the triple bagging and solar heater with triple bagging remained dominated by improved ash storage--even when their assumed level of protection is increased from 3 to 1.5%. By adopting improved ash storage, farmers capture the greatest benefit from improved storage technology--minimal additional benefits are gained from marginal additional improvements in storage protection.

Cost Parameters

The sensitivity analysis of the cost of the improved storage technologies also greatly influence their profitability. Relatively small variations (+/- 25%) in their cost generate relatively large differences in their feasibility. Therefore, farmer adoption will require farmer access to the necessary inputs (e.g., earthenware cannaries, plastic bags) at modest prices. For example, if plastic bags became available at a lower cost (25% lower), then this storage method would be attractive to more "advanced" farmers.

Finally, the assumed opportunity cost of capital (3%/month) assigned to the improved storage technologies did not have a large impact on the profitability of the improved ash or triple bag storage technologies. However, if a farmer were required to borrow cash (or valued his/her own capital) at a very high interest (i.e., 100% annually) then this would greatly reduce his/her incentive to adopt improved storage.

5.2.2.4 Storage for Future Sale: Base Run

Currently, a few high cowpea production household produce enough cowpeas to meet consumption needs and still have sufficient surplus grain for speculation. As new high-yielding varieties become available more farmers will grow cowpeas mainly as a cash crop, and may wish to store the crop until prices are highest in July-August. Experiments show high levels of bruchid damage after several months of storage, suggesting that "advanced" farmers with large inventories who store for 6 or more months (until the cowpea grain price peaks) using their current storage technology (e.g., sacks) will experience large losses. Thus, these farmers may benefit from investing in/adopting the improved cowpea storage technologies.

Assuming "advanced" farmers store 200 kg of their harvest for speculation using their current storage technology, their inventories would be reduced to only 0.6 kg after 9 months (November through July) in storage (when the market price peaks at 196 CFA/kg), due to bruchid damage. By investing in improved cowpea storage technology, these households could reduce storage losses, which would enable them to extend their period of speculation (i.e., the ability to earn profits by storing and selling when the price is at its peak).

Because "advanced" farmers tend to have good access to extension services, the following analysis assumes they will use the improved storage technologies correctly and receive all (100%) of the potential benefits.

"Advanced" farmers adopting the improved storage technologies will gain an additional 180.9 and 190.1 kg of cowpea grain after nine months of storage using the improved ash and either the triple bag or solar heater with triple bag technologies, respectively.

To assess the likelihood that "advanced" farmers would find these new technologies economically viable (profitable), the average and marginal rate of return to investing in each of the improved cowpea storage technologies were estimated (Table 5.11).

These results show that when an "advanced" farmer values his/her own funds or borrows the funds at a monthly interest rate of 3% (base run), adopting the improved ash, triple bag, and solar heater with triple bag storage technology implies a 2,098, 1,440, and 1,178% average rate of return (ARR), respectively, to grain stored for future sale (i.e., 9 months of storage). These results suggest that adopting any one of the alternative improved/new grain storage technologies would by economically attractive for the "advanced" farmer, since all far exceed the 50% minimum rate of return proposed by CIMMYT (1988).

Compared to the "advanced" farmers' current storage technology, improved ash gives a marginal ROR of 3,187%. In other words, by investing an additional 1,075 CFA in ash storage, benefits are increased to 34,263 CFA. Thus, the marginal ROR (34,263 divided by 1,075 CFA) equals 3,187%--suggesting a very attractive investment option.

The triple bag storage has a high (1,440%) ARR, it has a MRR of only 124%, yet still greater than the minimal acceptable 50% as suggested by CIMMYT. In order to adopt the triple bagging storage technology, the farmer would have to invest an additional 806 CFA (above the cost of the ash technology); but he/she would earn only 998 CFA more profit (net benefits) from investing the in the triple bag technology, compared to ash storage.

Similarly, although the solar heater with triple bagging technology has a high (1,178%) ARR, it generates less net benefits (-497)--compared to the triple bagging--and is therefore, dominated by the triple bag technology.

In summary, the base run analysis shows that although all three improved storage technologies give attractive ARRs, the MRR analysis shows that if an "advanced" farmer could adopt improved ash storage, he/she would earn a very large (3,187%) rate of return on this investment. And, if the farmer could invest an additional 806 CFA in triple bag storage, he/she would earn an additional 124% rate of return on this investment. Yet, it would be irrational for the farmer to invest in the solar heater with triple bag storage, since it is dominated by triple bag storage. These results are largely driven by the storage loss data used in the analysis. Available experimental data (Table 3.5) show that the triple bag and solar heater with triple bag technology are equivalent in terms of loss reduction, but the latter is more costly to adopt.

Table 5.11 Partial Budget and Rate of Returns Analysis of Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]: Base Run for Advanced Farmers.

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved[f] (kgs)	0.6	180.9	190.1	190.1
Partial Budget (CFA)				
Gross Benefits[g]	118	35,456	37,260	37,260
Total Costs[h]	1,613	8,063	2,419	3,414
Annual Costs[i]	538	1,613	2,419	2,916
Net Benefits (gross benefits minus annual costs)	-420	33,843	34,841	34,344
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	34,263	998	-497
Additional Annual Costs	NA	1,075	806	497
Rate of Returns (%)				
Average	-78	2,098	1,440	1,178
Marginal	NA	3,187	124	D

[a]200 kg of cowpea grain put into storage for nine months.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]Additional kg of cowpea grain as a result of using the improved technologies.
[g]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[h]Includes opportunity cost of capital (3% per month) for 10 months (Nov. - August).
[i]Total costs/useful life of the technology.
NA = not applicable; D = dominated.

5.2.2.5 Storage for Future Sale: Sensitivity Analysis

Although the base run represents the "best estimate" of the average and marginal returns to cowpea grain storage technologies, sensitivity analysis is conducted to test the variability in rate of return, associated with alternative assumptions regarding the data values used in these analyses. Further, given that some data used in the analysis are based on "informed assumptions" rather than empirical findings, sensitivity analysis indicated the degree to which each assumption affects the results.

Six parameters[42] were identified as having a significant influence on the rates of return to the improved grain storage technologies (Tables 5.12 - 5.14). Six sensitivity analyses are presented below. Each analysis assesses the impact of altering one of the six "critical parameters" on the rate of return to investing in the three new technologies--improved ash storage, triple bagging storage, and solar heater with triple bag storage.

Run 1: Farmers' Current Level of Storage Losses

In the base run analysis, annual storage losses were estimated using a logistic function (Equation 5.1), based on farm-level storage loss data collected in March 1990. By testing the robustness of these estimates, sensitivity analysis determines to what degree the rate of return estimate depends on the accuracy of these data.

Improved Ash Storage

In the base run analysis, "advanced" farmers adopting improved ash storage earned a 2,098% ARR and a 3,187% MRR on their investment (Table 5.11). When the assumed level of "advanced" farmers' current storage losses is increased by 50% (10.5%

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[42]The six parameters varied in the sensitivity analysis include the household's current level of grain losses using his/her traditional storage method, the losses associated with using the improved technologies, technology cost, market price of cowpea grain, the opportunity cost of capital, and a premium price paid for improved quality cowpea grain.

of the stock lost by the fourth month in storage vs. 7% in the base run), the ARR increases 6 percentage points to 2,104% and the MRR to ash storage increases 18 percentage points to 3,205%. This is because when household losses are increased by 50%, the amount of grain "saved" using farmers' current storage technology is reduced (0.6 kg in the base run vs. 0.15 kg) and consequently makes the improved ash technology marginally more attractive (180.9 kg "saved" in the base run vs. 181.4 kg).

In contrast, when the assumed level of household losses are decreased by 50% (3.5% of the stock lost by the fourth month in storage vs. 7% in the base run), the ARR decreases 42 percentage points to 2,056% and the MRR to ash storage decreases 127 percentage points to 3,060%. This is because when household losses are reduced by 50%, the amount of grain "saved" using farmers' current storage technology is increases (0.6 kg in the base run vs. 4.1 kg), which makes the improved ash technology marginally less attractive (180.9 kg "saved" vs. 177.4 kg).

Triple Bag Storage

In the base run, "advanced" farmers adopting triple bag storage earned a 1,440% ARR and the MRR was 124% (Table 5.11). When the assumed level of "advanced" farmers' current storage losses is increased by 50%, the ARR increases 4 percentage points to 1,444% and the MRR remains 124%. The MRR does not increase because when assumed household losses are increased by 50%, both the improved ash (180.9 kg "saved" in the base run vs. 181.4 kg) and triple bagging (190.1 kg "saved" in the base run vs. 190.6 kg) technology save an additional 0.5 kg of grain. Therefore, triple bagging is only improved on the average, but not marginally.

When "advanced" farmers' assumed level of losses is decreased by 50%, the ARR decreases 28 percentage points to 1,412% and the MRR to triple bagging remains 124%.

This is because when household losses are decreased by 50%, both the improved ash (180.9 kg "saved" in the base run vs. 177.4 kg) and triple bagging (190.1 kg in the base run vs. 186.6 kg) technologies "save" 3.5 kg less additional grain and therefore, the triple bag technology is only less attractive on the average, but not on the margin.

Solar Heater with Triple Bag Storage

In the base run, "advanced" farmers adopting the solar heater with triple bagging storage earned a 1,178% ARR, but the MRR was dominated by triple bag storage (Table 5.11). When the assumed level of "advanced" farmers' current storage losses is increased by 50%, the ARR increases 3 percentage points to 1,181% and the MRR remains dominated. This is because when household losses are increased by 50%, all three improved technologies "save" an additional 0.5 kg of grain and therefore, solar heater with triple bagging is only improved on the average (190.1 kg in the base run vs. 190.6 kg) and not on the margin.

When "advanced" farmers' assumed losses are decreased by 50%, the ARR decreases 24 percentage points to 1,154% and the MRR to solar heater with triple bag storage remains dominated. This is because when household losses are decreased by 50%, all three improved technologies "save" 3.5 kg less additional grain and therefore, the solar heater with triple bagging is only less attractive on the average (190.1 kg in the base run vs. 186.6 kg), but not on the margin.

<u>Run 2: Improved Storage Technology Protection</u>

In the base run analysis, the level of protection data were based on on-farm demonstrations of the improved storage technologies. Because so few trials were conducted, the sensitivity of the returns in the base run to the assumed protection levels are evaluated.

Improved Ash Storage

When the estimated level of losses using the improved ash storage is increased by 50% (9% of the stock lost by the third month in storage vs. 6% in the base run), the ARR decreases by 41 percentage points to 2,057% and the MRR decreases by 62 percentage points to 3,125%. This observed decrease in returns to adopting ash storage occurs because assuming 50% more "losses" under the improved ash technology results in less grain "saved" (177.5 kg vs. 180.9 kg in the base run), which is valued at the month 10 (August) market price of 196 CFA/kg. Since the traditional storage practice (i.e., cloth sacks) is being replaced by the improved ash storage, an increase in the value of this parameter (i.e., less effective) will result in a lower rate of return. By setting a lower protection level for the improved ash storage technology, the improved ash storage technology will certainly appear worse than in the base run.

When the estimated level of losses using improved ash storage is decreased by 50% (3% of the stock lost by the third month in storage vs. 6% in the base run), the ARR increases by 40 percentage points to 2,138%, and the MRR increases by 60 percentage points to 3,247%. Setting a higher protection level for the improved ash storage technology, results in more grain "saved" (184.2 kg vs. 180.9 kg in the base run), which is valued at the month 10 (August) market price of 196 CFA/kg.

Triple Bag Storage

When the estimated level of losses using triple bagging storage is increased by 50% (i.e., 4.5% of the stock lost by the third month in storage), the ARR decreases by 27 percentage points to 1,413% and the MRR increases by 41 percentage points to 165%. Intuitively, one would believe that the marginal returns to the triple bag storage technology should also decrease when the level of storage losses using triple bag storage are increased by 50%. Yet, the MRR increases because the percentage decrease in "saved" grain (1.82%) using triple bag storage (186.7 kg vs. 190.1 kg in the base run) is less than the percentage decrease in "saved" grain (1.92%) using improved ash storage (177.5 kg vs. 180.9 kg in the base run).

When the estimated level of losses using triple bagging storage is decreased by 50% (1.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR increases by 14 percentage points to 1,454% and the MRR decreases by 39 percentage points to 85%. Intuitively, one would believe that the marginal returns to the triple bag storage technology should also increase when the level of storage losses using triple bag storage are decreased by 50%. Yet, the MRR increases because the percentage increase in "saved" grain (0.89%) using triple bag storage (191.8 kg vs. 190.1 kg in the base run) is less than the percentage increase in "saved" grain (1.79%) using improved ash storage (184.2 kg vs. 180.9 kg in the base run).

Solar Heater with Triple Bag Storage

When the estimated level of solar heater with triple bag storage losses is increased by 50% (4.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR decreases by 23 percentage points to 1,155% and the MRR remains dominated. Setting a 50% lower protection level for the solar heater with triple bagging technology, results in less grain "saved" (186.7 kg), and in turn, a lower rate of return.

When the estimated level of the solar heater with triple bag storage losses is decreased by 50% (1.5% of the stock lost by the third month in storage vs. 3% in the base run), the ARR increases by 11 percentage points to 1,189% and the MRR remains dominated. Setting a 50% higher protection level for the solar heater with triple bagging technology, results in more grain "saved" (191.8 kg), and in turn, a higher rate of return.

<u>Run 3: Improved Storage Technology Cost</u>

In the base run analysis, although most cost figures of the improved storage technology were directly quoted from CRSP documents, there is still a possibility that these costs were under/over estimated. The cost variable is varied to estimate how sensitive the returns to improved grain storage technologies are to higher or lower total input costs.

Improved Ash Storage

When the total input cost of the improved ash storage technology is increased by 25%, the ARR decreases by 439 percentage points to 1,659% and the MRR decreases by 696 percentage points to 2,491%. This observed decrease in the rate of return to improved ash are expected because the benefits (180.9 kg of grain "saved") have not changed, but the cost of adopting the improved ash storage technology is now 25% higher.

When the total input cost of the improved ash storage technology is decreased by 25%, the ARR increases by 732 percentage points to 2,830% and the MRR increases by 1,092 percentage points to 4,279%. This observed increase in the rate of return to improved ash is again expected because the benefits (180.9 kg of grain "saved") have not changed, but the cost of adopting the improved ash storage technology is now 25% lower.

Triple Bag Storage

When the total input cost of the triple bag storage technology is increased by 25%, the ARR decreases by 308 percentage points to 1,132% and the MRR decreases by 45 percentage points to 79%. This observed decrease in the ARR and MRR to triple bagging is expected because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the triple bag storage technology is now 25% higher.

When the total input cost of the triple bag storage technology is decreased by 25%, the ARR increases by 514 percentage points to 1,954% and the MRR increases by 75 percentage points to 199%. This observed increase in the ARR and MRR to triple bagging is again expected because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the triple bag storage technology is now 25% lower.

Solar Heater with Triple Bag Storage

When the total input cost of the solar heater with triple bag storage technology is increased by 25%, the ARR decreases by 256 percentage points to 922% and the MRR remains dominated. The ARR to the solar heater with triple bagging decreases because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the solar heater with triple bag storage technology is now 25% higher.

When the total input cost of the solar heater with triple bag storage technology is decreased by 25%, the ARR increases by 426 percentage points to 1,604% and the MRR remains dominated. This observed increase in the ARR is again expected because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the solar heater with triple bag storage technology is now 25% lower.

Run 4: Market Price of Cowpea Grain

In the base run analysis, the market price for cowpea grain was based on two years of price data (1989-1990) collected by the TLU. Because market prices vary across years and across markets, the grain price is varied to estimate how sensitive the returns to improved grain storage technologies are to price.

Improved Ash Storage

When the market price for cowpea grain is increased by 25%, (from 196 to 245 CFA/kg) the ARR increases by 550 percentage points to 2,648% and the MRR increases by 822 percentage points to 4,009%. This observed increase in the rate of return to improved ash are expected because the benefits (180.9 kg of grain "saved" times a higher price) have increased, but the cost of adopting the improved ash storage technology has not changed.

When the market price for cowpea grain is decreased by 25%, (from 196 to 147 CFA/kg) the ARR decreases by 549 percentage points to 1,549% and the MRR decreases by 822 percentage points to 2,365%. This observed decrease in the rate of return to improved ash is again expected because the benefits (180.9 kg of grain "saved" times a lower price) have decreased, but the cost of adopting the improved ash storage technology has not changed.

Triple Bag Storage

When the market price for cowpea grain is increased by 25%, the ARR increases by 385 percentage points to 1,825% and the MRR increases by 56 percentage points to 180%. This observed increase in the rate of return to triple bagging is expected because the benefits (190.1 kg of grain "saved" times a higher price) have increased, but the cost of adopting the triple bag storage technology has not changed.

When the market price for cowpea grain is decreased by 25%, the ARR decreases by 385 percentage points to 1,055% and the MRR decreases by 56 percentage points to 68%. This observed decrease in the rate of return to triple bagging is again expected because the benefits (190.1 kg of grain "saved" times a lower price) have increased, but the cost of adopting the triple bagging storage technology has not changed.

Solar Heater with Triple Bag Storage

When the market price for cowpea grain is increased by 25%, the ARR increases by 319 percentage points to 1,497% and the MRR remains dominated. This observed increase in the rate of return to the solar heater with triple bagging is expected because the benefits (190.1 kg of grain "saved" times a higher price) have increased, but the cost of adopting the solar heater with triple bag storage technology has not changed.

When the market price for cowpea grain is decreased by 25%, the ARR decreases by 320 percentage points to 858% and the MRR remains dominated. This observed decrease in the rate of return to the solar heater with triple bagging is again expected because the benefits (190.1 kg of grain "saved" times a lower price) have increased, but the cost of adopting the solar heater with triple bagging storage technology has not changed.

Run 5: Interest Rate/Opportunity Cost of Capital

In the base run analysis, the opportunity cost of capital is set at a 3 percent per month interest rate, representing the interest rate that farmers would have to pay if they borrowed from money lenders or informal credit institutions. The opportunity cost of capital is an additional cost to the farmer of adopting any of the improved storage technologies and affects the returns to the improved/new technologies. Because farmers may have to pay more/less interest to finance their investment the interest is varied to test how sensitive the returns to improved storage are to the interest rate.

Improved Ash Storage

When the monthly interest rate for capital invested in improved ash storage is increased by 50% (from 3 to 4.5%), the ARR decreases by 296 percentage points to 1,802% and the MRR decreases by 444 percentage points to 2,743%. This observed decrease in the rate of return to improved ash results from an increase in the cost of adopting the improved ash storage, while the benefits (180.9 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in improved ash storage is decreased by 50% (from 3 to 1.5%), the ARR increases by 347 percentage points to 2,445% and the MRR increases by 517 percentage points to 3,704%. This observed increase in the rate of return to improved ash is expected because the benefits (180.9 kg of grain "saved") have not changed, but the cost of adopting the improved ash storage technology has decreased.

Triple Bag Storage

When the monthly interest rate for capital invested in triple bag storage is increased by 50%, the ARR decreases by 207 percentage points to 1,233% and the MRR decreases by 30 percentage points to 94%. This observed decrease in the rate of return to triple bagging results from an increase in the cost of triple bag storage, while the benefits (190.1 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in triple bag storage is decreased by 50%, the ARR increases by 244 percentage points to 1,684% and the MRR increases by 35 percentage points to 159%. This observed increase in the rate of return to triple bag storage is expected because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the triple bag storage technology has decreased.

Solar Heater with Triple Bag Storage

When the monthly interest rate for capital invested in the solar heater with triple bagging storage is increased by 50%, the ARR decreases by 172 percentage points to 1,006% and the MRR remains dominated. This observed decrease in the ARR to the solar heater with triple bag storage results from an increase in the cost of adopting the technology, while the benefits (190.1 kg of grain "saved") remain unchanged.

When the monthly interest rate for capital invested in the solar heater with triple bagging storage is decreased by 50%, the ARR increases by 202 percentage points to 1,380% and the MRR remains dominated. This observed increase in the ARR to the solar heater with triple bag storage results because the benefits (190.1 kg of grain "saved") have not changed, but the cost of adopting the solar heater with triple bag storage technology has decreased.

Run 6: Solar Heater with Triple Bag Storage Provides 100% Protection

In the base run analysis, the solar heater with triple bagging storage technology's protection level was set equal to the triple bagging storage technology because data from the on-farm demonstrations of the improved storage technologies show the two technologies to be equally effective (Table 3.5). Intuitively one would expect that using the solar heater with triple bag technology would result in lower losses than triple bagging alone because the bruchids are first killed before the grain is put into plastic bags, and laboratory experimental results/data suggest that the solar heater with triple bagging storage technology provides 100% protection. Run 6 analyses the profitability of the solar heater with triple bagging technology, under the assumption of 100% protection. Since this assumption only affects the profitability of the solar heater with triple bag technology, Run 6 applies to only this technology (Table 5.14).

Solar Heater with Triple Bag Storage

When the solar heater with triple bag technology protection is 100%, the ARR to the solar heater with triple bag storage increases 62 percentage points to 1,244% and the MRR (i.e., compared to triple bagging) increases 267 percentage points to 267%.

Run 7: Premium for Improved Quality Cowpea Grain

In the base run analysis, the grain "saved" (benefits to) using each of the improved storage technologies was valued at the stated peak market price. To account for farmer and consumer preferences for undamaged (without holes or not "weevily" favored) cowpea grain, a premium of 20% above the market price is given to the grain "saved" using the improved storage technologies.

Improved Ash Storage

When a 20% premium is paid for undamaged cowpea grain, the ARR to improved ash storage increases 440 percentage points to 2,538% and the MRR increases 660 percentage points to 3,847%.

Triple Bag Storage

When a 20% premium is paid for undamaged cowpea grain, the ARR to triple bag storage increases 308 percentage points to 1,748% and the MRR increases 44 percentage points to 168%.

Solar Heater with Triple Bag Storage

When a 20% premium is paid for undamaged cowpea grain, the ARR to the solar heater with triple bag storage increases 255 percentage points to 1,433%, but the MRR remains dominated.

5.2.2.6 Storage for Future Sale: Summary

The sensitivity analysis shows that for an "advanced" farmer storing 200 kg for speculation, the rates of return to improved ash and triple bagging are most affected by variations in input cost, the market price of cowpea grain and the opportunity cost of capital assigned to the investment.

Cost Parameters

The returns to the improved ash and triple bag technologies are most sensitive to fluctuations (+/- 25%) in their cost. When the input cost of improved ash was increased 25% from 1,200 to 1,500 CFA, the ARR (MRR) diminished to 1,659% (2,491%), compared to 2,098% (3,187%) in the base run. When the input cost of triple bagging was increased 25% from 1,800 to 2250 CFA, the ARR (MRR) diminished to 1,132% (79%), compared to 1,440% (124%) in the base run. On the other hand, when the input cost of improved ash was decreased 25% from 1,200 to 900 CFA, the ARR (MRR) increased to 2,830% (4,279%), compared to 2,098% (3,187%) in the base run. When the input cost of triple bagging was decreased 25% from 1,800 to 1,350 CFA, the ARR (MRR) increased to 1,954% (199%), compared to 1,440% (124%) in the base run.

Similarly, relatively small changes in cowpea grain resulted in relatively large differences in the technologies profitability. When the market price was increased 25%, from 196 to 245 CFA/kg, the improved ash technology gave an ARR (MRR) of 2,648% (4,009%), compared to 2,098% (3,187%) in the base run. When the market price of cowpea grain increased from 196 to 245 CFA/kg, the triple bagging technology gave an ARR (MRR) of 1,825% (180%), compared to 1,440% (124%) in the base run. On the other hand, when the market price of cowpea grain decreased from 196 to 147 CFA/kg, the improved ash technology gave an ARR (MRR) of 1,549% (2,365%), compared to 2,098% (3,187%) in the base run. When the market price of cowpea grain decreased from 196 to 147 CFA/kg, the triple bagging technology gave an ARR (MRR) of 1,055% (68), compared to 1,440% (124%) in the base run. Furthermore, the grain prices used in the analysis were market prices and not farmgate prices (the price farmers would receive for the sale of their grain) because this data was not available. Thus, the estimated profitability of the technologies is inflated, if the farmgate prices are significantly below market prices. Also, grain prices vary throughout the season and across markets. Thus, the farmer's decision to adopt an improved storage technology will depend on farmers' future price expectations at harvest when they must decide whether to adopt improved storage.

Finally, the assumed opportunity cost of capital (3%/month) assigned to the improved storage technologies did have a large impact on the profitability of the improved ash and triple bag storage technologies. When the opportunity cost of capital was increased 50%, from 3 to 4.5% per month, the improved ash technology gave an ARR (MRR) of 1,802% (2,743%), compared to 2,098% (3,187%) in the base run. When the opportunity cost of capital was increased 50%, the triple bagging technology gave an ARR (MRR) of 1,233% (94%), compared to 1,440% (124%) in the base run. On the other hand, when the opportunity cost of capital was decreased 50%, from 3 to 1.5% per month, the improved ash technology gave an ARR (MRR) of 2,445% (3,704%), compared to 2,098% (3,187%) in the base run. When the opportunity cost of capital was decreased 50%, the triple bagging technology gave an ARR (MRR) of 1,684% (159%), compared to 1,440% (124%) in the base run.

Benefit Parameters

Interestingly, the rates of return to the improved ash and triple bagging technologies were not very sensitive to variations (+/- 50%) in the level of protection generated by either the farmers' current storage practices (sacks) or the improved storage technologies. When the assumed level of farmers' losses was increased from 7 to 10.5%, the improved ash storage technology gave an ARR (MRR) of 2,104% (3,205%), compared to 2,098% (3,187%) in the base run. When the assumed level of farmers' losses was increased 50%, the triple bagging storage technology gave an ARR (MRR) of 1,444% (124%), compared to 1,440% (124%) in the base run. On the other hand, when the assumed level of farmers' losses was decreased from 7 to 3.5%, the improved ash storage technology gave an ARR (MRR) of 2,056% (3,060%), compared to 2,098% (3,187%) in the base run. When the assumed level of farmers' losses was decreased 50%, the triple bagging storage technology gave an ARR (MRR) of 1,412% (124%), compared to 1,440% (124%) in the base run.

Table 5.12 Sensitivity Analysis: "Advanced" Farmer Using **Improved Ash Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Losses using farmer's technology (kg)[a]	199.4	b[b] +/- 50%	b	b	b	b	b
Losses using improved ash technology (kg)[c]	18.5	b	b +/- 50%	b	b	b	b
Cost of improved ash technology per unit (CFA)	1,613	b	b	b +/- 25%	b	b	b
Market price of cowpea grain (CFA/kg)	196	b	b	b	b +/- 25%	b	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%	b
20% premium price for improved quality cowpea grain	196	b	b	b	b	b	b + 20%
ARR (%) for:	2,098						
· decrease in value of variable		2,056	2,138	2,830	1,549	2,445	
· increase in value of variable		2,104	2,057	1,659	2,648	1,802	2,538
Change in ARR from base run, due to:							
· decrease in value of variable		-42	+40	+732	-549	+347	
· increase in value of variable		+6	-41	-439	+550	-296	+440
MRR (%) for:	3,187						
· decrease in value of variable		3,060	3,247	4,279	2,365	3,704	
· increase in value of variable		3,205	3,125	2,491	4,009	2,743	3,847
Change in MRR from base run, due to:							
· decrease in value of variable		-127	+60	+1,092	-822	+517	
· increase in value of variable		+18	-62	-696	+822	-444	+660

[a]Storage of 200 kg intended for sale in cloth sacks.
[b]"b" represents base run values for the variable.
[c]Storage of 200 kg intended for sale using improved ash storage technology.
Note: See Appendix Tables A12 - A18 for calculations supporting these results.

Table 5.13 Sensitivity Analysis: "Advanced" Farmer Using **Triple Bag Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Losses using farmer's technology (kg)[a]	199.4	b[b] +/- 50%	b	b	b	b	b
Losses using triple bag technology (kg)[c]	9.3	b	b +/- 50%	b	b	b	b
Cost of triple bag technology per unit (CFA)	2,419	b	b	b +/- 25%	b	b	b
Market price of cowpea grain (CFA)	196	b	b	b	b +/- 25%	b	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%	b
20% premium for improved quality cowpea grain	196	b	b	b	b	b	b + 20%
ARR (%) for: • <u>decrease</u> in value of variable • <u>increase</u> in value of variable	1,440	 1,412 1,444	 1,454 1,413	 1,954 1,132	 1,055 1,825	 1,684 1,233	 1,748
Change in ARR from base run, due to: • <u>decrease</u> in value of variable • <u>increase</u> in value of variable		 -28 +4	 +14 -27	 +514 -308	 -385 +385	 +244 -207	 +308
MRR (%) for: • <u>decrease</u> in value of variable • <u>increase</u> in value of variable	124	 124 124	 85 165	 199 79	 68 180	 159 94	 168
Change in MRR from base run, due to: • <u>decrease</u> in value of variable • <u>increase</u> in value of variable		 0 0	 -39 +41	 +75 -45	 -56 +56	 +35 -30	 +44

[a]Storage of 200 kg intended for sale in cloth sacks.
[b]"b" represents base run values for the variable.
[c]Storage of 200 kg intended for sale using triple bag storage technology.
Note: See Appendix Tables A12 - A18 for calculations supporting these results.

Table 5.14 Sensitivity Analysis: "Advanced" Farmer Using **Solar Heater with Triple Bagging Storage Technology**, Values of Key Parameters and Subsequent Changes in the ARR and MRR, northern Cameroon.

Key Variables	Base Run	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
Losses using farmer's technology (kg)[a]	199.4	b[b] +/- 50%	b	b	b	b	b	b
Losses using solar heater with triple bag technology (kg)[c]	9.3	b	b +/- 50%	b	b	b	b = 0	b
Cost of solar heater with triple bag technology per unit (CFA)	2,916	b	b	b +/- 25%	b	b	b	b
Market price of cowpea (CFA)	196	b	b	b	b +/- 25%	b	b	b
Monthly opportunity cost of capital/interest rate (%)	3	b	b	b	b	b +/- 50%	b	b
20% premium price for improved quality cowpea grain	196	b	b	b	b	b	b	b + 20%
ARR (%) for:	1,178							
• <u>decrease</u> in value of variable		1,154	1,189	1,604	858	1,380	1,244	
• <u>increase</u> in value of variable		1,181	1,155	922	1,497	1,006		1,433
Change in ARR from:								
• <u>decrease</u> in value of variable		-24	+11	+426	-320	+202	+62	
• <u>increase</u> in value of variable		+3	-23	-256	+319	-172		+255
MRR (%) for:	D[d]							
• <u>decrease</u> in value of variable		D	D	D	D	D	267	
• <u>increase</u> in value of variable		D	D	D	D	D		D
Change in MRR from:								
• <u>decrease</u> in value of variable		D	D	D	D	D	+267	
• <u>increase</u> in value of variable		D	D	D	D	D		D

[a]Storage of 200 kg intended for sale in cloth sacks.
[b]"b" represents base run values for the variable.
[c]Storage of 200 kg intended for sale using the solar heater with triple bag storage technology.
[d]"D" represents a dominated treatment.
Note: See Appendix Tables A12 - A18 for calculations supporting these results.

5.3 The Store vs. Selling Decision

Risk and the Opportunity Cost of Holding Grain Inventories

As in most developing countries, the market price of cowpeas in the Cameroon increases substantially after harvest. This phenomena suggests that farmers could profit by storing grain and selling it later in the season when post-harvest prices increase to their seasonal high level. For example, the previous analysis indicated that "advanced" farmers who stored 200 kg of cowpeas for future sale, using improved ash and triple bag storage, would have earned attractive average and marginal rates of return, compared to their existing storage technology. But this analysis didn't take into account either the risk associated with adopting these improved storage technologies or the opportunity cost of the income farmers would have foregone, had they chosen to hold their inventories several months as required to capture the higher late-season market price.

Risk

Storing stocks for future sale exposes farmers to both "storage" and "price" risk. For example, under optimal conditions, farmers adopting the improved storage technologies (e.g., triple plastic bags) will reduce their insect infestation. But, under actual farm-level storage conditions, rodents may chew through the hermetically sealed bags--allowing reinfestation. If this were to occur, the benefits to adopting triple bag storage would be substantially less than previously projected. Similarly, while historical data used in this analysis indicates that prices rise over the season, the magnitude of the monthly price rise varies between market and between years. In years of short supply (poor harvest), the prices rise will exceed the mean values used; and in years of abundant supply (good harvest) the price rise will be below the mean. Hence, assuming that poor farmers are risk averse, they would likely discount the projected potential benefit--given these elements of risk.

On the other hand, by selling at harvest a farmer can obtain cash immediately, thereby improving his/her cash flow. In addition, he/she is not forced to borrow cash at high informal credit market rates in order to cover outstanding debts and immediate household needs; while waiting to sell his/her grain at the seasonal high price.

Opportunity Cost of Stored Inventories

By postponing sale at harvest to obtain a greater future benefit, a farmer forgoes the opportunity to immediately use the cash he/she could have gained by selling at harvest. Therefore, in order to compare the "true" value of this future income to the value of the income he/she could have earned by selling at harvest, this future income must be discounted.

Since the previous results indicated that the most profitable new storage technology was improved ash storage, the following analysis only evaluates the profitability of this technology, when an opportunity cost is assigned to the value of the farmers' stored grain. In this analysis, projected future income (net returns) is discounted by two alternative rates, 18% (1.5% per month) and 36% (3.0% per month). All other costs and benefit streams are as specified in the base analysis presented earlier.

Tables 5.15 and 5.16 present the net present value (NPV) of the future income that a farmer would earned, if he/she sold the crop in November through October. The respective NPVs may be interpreted as the current value (November) of the respective future incomes (net returns). For storage for future sale to more profitable than sale at harvest, the NPV in a given month must be greater than the net return that a farmer could have earned by selling at harvest (November).

The results show that for an "advanced" farmer using improved ash technology to store 200 kg of cowpeas, under the assumption that the opportunity cost of capital is 3% (e.g., discount rate), the NPV of stored grain sold in all months is below the value of the net returns he/she would have earned if he/she had sold the crop at harvest (Figure 5.3 and Table 5.15).

On the other hand, when the discount rate is reduced to 1.5% per month, the NPV of the future net returns is less that the net returns that a farmer could have earned by selling at harvest in all months except August. This suggests that only if a farmer stored and sold his crop in August, would he/she have earned more profit (29,589 CFA) than by selling at harvest (27,600 CFA). But, the value of this additional profit was equal to approximately 2,000 CFA--compared to an investment cost of 6,000 CFA (Figure 5.4 and Table 5.16).

These results suggest provide insights as to why farmers typically sell their cowpea surpluses at harvest. Storage for future sale exposes farmers to risk and they are short of cash at harvest. Therefore, few poor farmers can afford to store in anticipation of the modest and uncertain profits associated with storing for speculation.

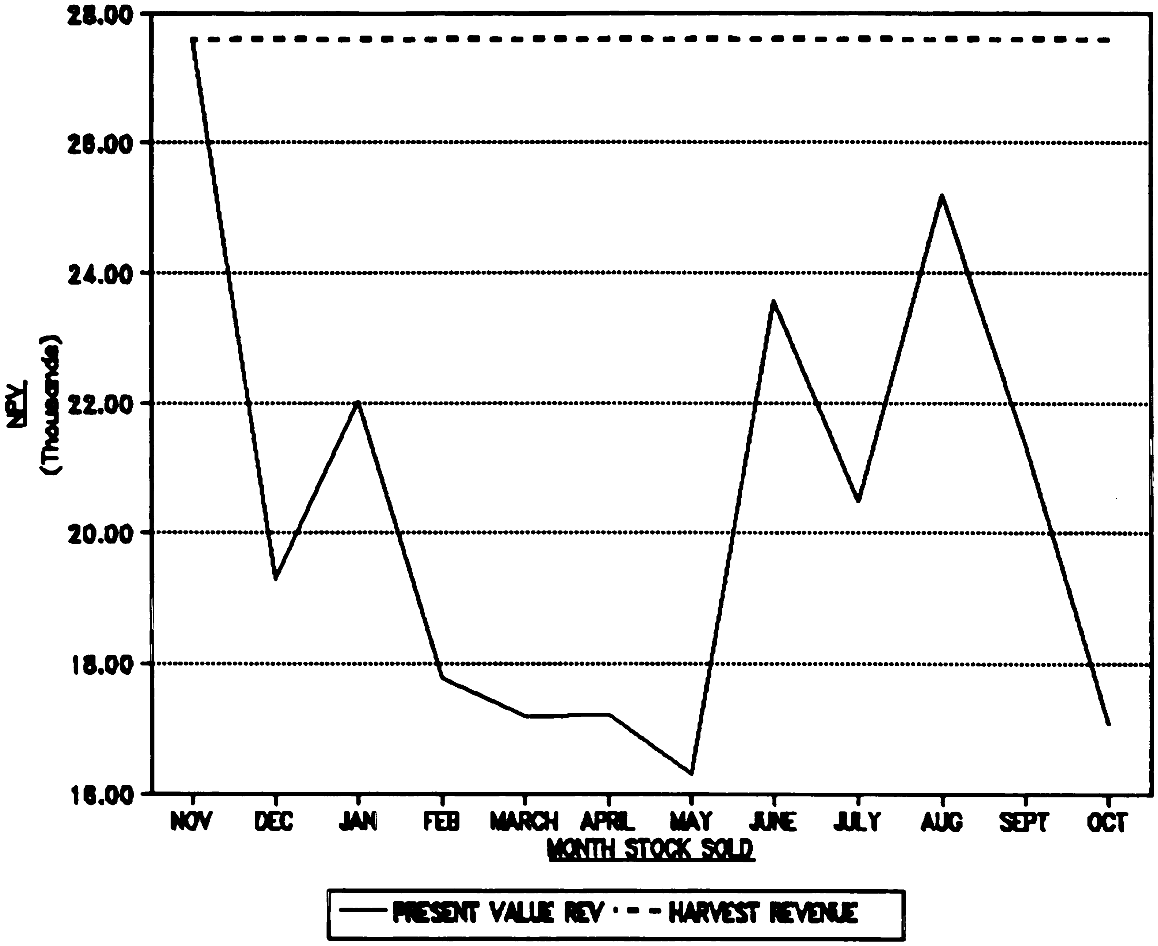

Figure 5.3 Net Present Value (3% Per Month Discount Rate) of Grain Sold in Respective Month.

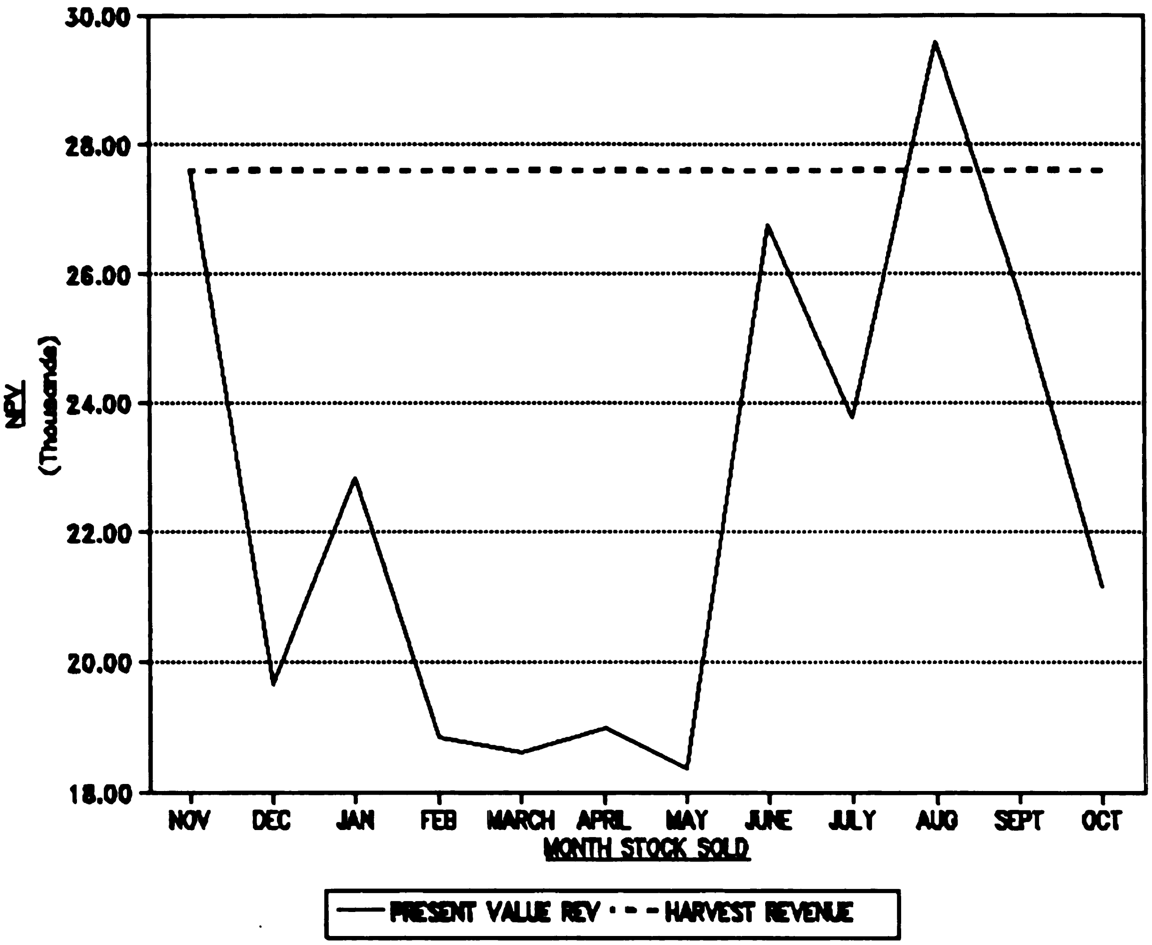

Figure 5.4 Net Present Value (1.5% Discount Rate Per Month) for Grain Sold in Respective Month.

Table 5.15 Net Present Value (3% Discount Rate) of the Net Returns to Stored Grain in the Respective Month Sold.

	Sell Nov 1	Invest in Improved Ash	Sell Dec 1	Sell Jan 1	Sell Feb 1	Sell March 1	Sell April 1	Sell May 1	Sell June 1	Sell July 1	Sell Aug 1	Sell Sept 1	Sell Oct 1
Benefits (CFA)													
Quantity in Store (kg)	200		199.37	197.66	193.12	181.54	181.54	181.54	181.54	181.54	181.54	181.54	181.54
Market Price	138		101	121	105	113	118	117	171	156	196	175	149
Gross Revenue	27,600		20,136	23,917	20,278	20,514	21,422	21,240	31,043	28,320	35,582	31,770	27,049
Salvage Value[a]	0		5,900	5,800	5,700	5,600	5,500	5,400	5,300	5,200	5,100	5,000	4,900
Total Revenue	27,600		26,036	29,717	25,978	26,144	26,922	26,640	36,343	33,520	40,682	36,770	31,949
Costs (CFA)													
Canneries[b]	0	6,000	0	0	0	0	0	0	0	0	0	0	0
Net Revenue	27,600	-6,000	26,036	29,717	25,978	26,114	26,922	26,640	36,343	33,520	40,682	36,770	31,949
Discount Factor[c]	1		0.9708	0.9426	0.9151	0.8885	0.8626	0.8375	0.8131	0.7894	0.7664	0.7441	0.7224
Discounted Net Revenue	27,600	-6,000	25,278	22,011	23,773	23,202	23,223	22,311	29,550	26,461	31,179	27,360	23,081
NPV	27,600		19,278	22,011	17,773	17,202	17,223	16,311	23,550	20,461	25,179	21,360	17,081

[a]Depreciation on the cannaries, as of the month the grain was sold.
[b]4 canneries at 1,200 CFA each.
[c]3% per month.

Table 5.16 Net Present Value (1.5% Discount Rate) of the Net Returns to Stored Grain in the Respective Month Sold.

	Sell Nov 1	Invest in Improved Ash	Sell Dec 1	Sell Jan 1	Sell Feb 1	Sell March 1	Sell April 1	Sell May 1	Sell June 1	Sell July 1	Sell Aug 1	Sell Sept 1	Sell Oct 1
Benefits (CFA)													
Quantity in Store (kg)	200		199.37	197.66	193.12	181.54	181.54	181.54	181.54	181.54	181.54	181.54	181.54
Market Price	138		101	121	105	113	118	117	171	156	196	175	149
Gross Revenue	27,600		20,136	23,917	20,278	20,514	21,422	21,240	31,043	28,320	35,582	31,770	27,049
Salvage Value[a]	0		5,900	5,800	5,700	5,600	5,500	5,400	5,300	5,200	5,100	5,000	4,900
Total Revenue	27,600		26,036	29,717	25,978	26,144	26,922	26,640	36,343	33,520	40,682	36,770	31,949
Costs (CFA)													
Canneries[b]	0	6,000	0	0	0	0	0	0	0	0	0	0	0
Net Revenue	27,600	-6,000	26,036	29,717	25,978	26,114	26,922	26,640	36,343	33,520	40,682	36,770	31,949
Discount Factor[c]	1		0.9852	0.9707	0.9563	0.9422	0.9283	0.9145	0.9010	0.8877	0.8746	0.8617	0.8489
Discounted Net Revenue	27,600	-6,000	25,652	28,845	24,843	24,604	24,990	24,364	32,746	29,756	35,580	31,683	27,123
NPV	27,600		19,625	22,845	18,843	18,604	18,990	18,364	26,746	23,756	29,580	25,683	21,123

[a]Depreciation on the cannaries, as of the month the grain was sold.
[b]4 canneries at 1,200 CFA each.
[c]1.3% per month.

CHAPTER 6 SUMMARY AND CONCLUSIONS

This chapter is divided into three sections. The first summarizes the thesis and research findings for the benefit-cost analysis, noting important issues/points in interpreting the results. The second compares the rates of return estimated for the improved storage technologies under both the "traditional" and "advanced" farmers' situation/conditions, and reviews possible implications for the improved storage technologies developed. The final section suggests additional data that should be collected to confirm these results; describes the study's limitations and proposes future socioeconomic research to better inform farmer storage issues; and considers the policy implications of extending these improved grain storage technologies.

6.1 Thesis Summary

Scientists and policy makers have focused a great deal of attention on reducing post-harvest food losses as part of the overall strategy for coping with possible future food shortages in the developing world. Out of this concern, several international and national research institutions have conducted research to quantify the level and causes of on-farm food grain storage losses. Inadequate storage facilities have attributed to/been blamed for some/part of the grain losses.

Much of the research on improving small-farm grain storage has involved surveys and trials to assess the magnitude of current losses. Based on a review of the literature, the studies reviewed can be roughly separated into two groups--those claiming that on-farm grain storage losses are high (30-90%) and those supporting low (5-10%) losses. These accounts suggest that it is difficult to generalize regarding storage losses. The magnitude of storage losses varies by crop and from region-to-region. Therefore, crop location and system specific analysis is needed to accurately estimate storage losses for a particular case. Furthermore, the correlation between the magnitude of "actual" losses and storage time is greatly influenced by the households' consumption rate. Because the amount of grain a household stores is continually declining, the losses experienced affect a decreasing quantity of grain in storage.

In the tropics and subtropics, food grains are mostly stored using traditional methods, which vary in their ability to insure safe storage. Farmers use numerous traditional grain storage structures and protectants against insect pest damage to minimize on-farm storage losses. Performance variations are typically influenced by climate, local availability of suitable materials, labor availability, investment capital, and local customs (McFarlane, 1988). These traditional on-farm storage methods generally provide effective protection for the relatively small stores of grain low-resource farmers produce.

Cowpeas are the principal grain legume crop grown in northern Cameroon. Several parts of the plant are used by the household. Cowpea grain, leaves and hay are both home-consumed and sold. Although cowpea production accounts for only 5% of the harvested area of the Far North Province, for many households it fills an important niche during the "hungry season" (July-August), since cowpeas are practically the only "new crop" available during this early period.

Although research trials have produced monoculture yields of 2,000 kg/ha, farmers' average yields tend to be low (300-400 kg/ha). Part of this yield difference is due to the fact that farmers in northern Cameroon typically intercrop cowpeas with grains, which makes direct comparisons between monoculture and intercropped yields inappropriate. Also, farmers are often unable to obtain inputs (i.e., high-yielding variety seed and insecticide) needed to produce high yields under monoculture.

Several international and national research institutions have conducted cowpea research, focusing primarily on developing improved varieties with higher yield potential and increased storage-pest resistance, and improved on-farm grain storage technologies.

To better understand storage constraints facing farmers, the Bean/Cowpea CRSP conducted three farmer surveys which revealed considerable variations among cowpea farmers in northern Cameroon, in terms of technology adoption, level of production, household utilization and storage methods. Data collected on surveyed cowpea farmers (1990) were used to classify farmers according to their level of adoption of improved varieties and/or production recommendations extended by the research-extension system. The majority (78%) of cowpea farmers had either not adopted or not fully-adopted the recommended improved production technology/cropping practices[43]. A large proportion (47%) planted only traditional cowpea varieties, generally intercropping them

[43]If a woman was the primary person responsible for cowpea production, she generally did not spray insecticide (82%). Farmers' lack of access to insecticide (54%), and the lack of access to credit to purchase inputs (16%) were the most frequently given reasons/constraints for not using insecticide.

with either sorghum or millet, and did not spray insecticide on the crop in the field[44] . Generally, these non-adopting farmers are women who produce on average less than 100 kgs of cowpea grain, assumed primarily for home consumption.

A minority (22%) of cowpea farmers adopted the recommended improved production technologies/practices--monocropping an improved cowpea variety and applying field insecticides. These farmers produced an average of 287 kgs of cowpeas per household on 1.3 hectares.

In addition, samples of stored cowpeas were collected from all interviewed households and assessed for storage damage. Analysis of the loss data by field practices followed showed that farmers applying field insecticides suffered lower storage losses than farmers who either intercropped with cotton or monocropped.

Farmers' storage losses also varied with the storage method practiced. Most farmers stored under 100 kg of cowpea grain. Farmers who treated their inventories with insecticides and stored for 4 to 6 months in sacks incurred the lowest amount of storage loss, whereas cowpea grain stored in ash (traditional ash storage method) suffered the most damage--suggesting that farmers traditional ash storage treatment is not effective. Finally, losses in cowpeas stored on a danki provided approximately the same level of protection (after 4-6 months of storage) as ash--possible because cowpea

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[44]Cowpea leaves are an important food item for many households. Frequently, farmers who planted monoculture cowpeas and sprayed insecticide also intercropped cowpeas with a grain in order to have insecticide-free cowpea leaves to eat. Cowpea leaves may be almost as important as cowpea grain to a "traditional" farmer household. This is not really a constraint, but rather it's a reason for not adopting higher grain-yielding yet lower leaf-yielding varieties which require insecticide.

pods provide resistance to bruchid penetration and the sun may inhibit insect population growth.

In 1986, scientists at Purdue University and IRA (under the auspices of the Bean/Cowpea CRSP) initiated research to develop bruchid resistant varieties and improve farmers' post-harvest storage technologies. On-farm experiments in Maroua, Cameroon demonstrated that the improved ash, triple bag and solar heater with triple bag storage technologies effectively protected stored cowpea grain from *C. maculatus* infestations.

This thesis evaluates the profitability of these technologies using benefit-cost analysis to assess their potential attractiveness to different types of farmers--"traditional" and "advanced". Also this analysis was carried out to help guide future research efforts to develop appropriate technologies that meet the needs of limited resource farmers. Data from the farm surveys and on-farm trials were used to estimate cost and benefits associated with each storage technology. Also, the analysis took into account differences between farmer types with respect to management practices, capacity to bear risk, access to credit and extension services, and access to both input and output markets.

Both the average (ARR) and marginal rates of return (MRR) to adopting the improved storage technologies were calculated. The ARR indicated the percentage increase in returns above the investment cost. The MRR assessed the incremental profitability of a more costly technology, above and beyond the profitability of the less costly alternative.

Cost Parameter Assumptions

Several cost assumptions were incorporated into these analyses. First, the analysis assumed that the investment cost of a granary was zero because households do not construct/invest in a granary for the sole purpose of cowpea grain storage. Rather, households who store cowpea in a granary also use it to store other food grains/stuffs including millet and sorghum. Also, because no data were available to estimate construction/maintenance costs of a granary, no attempt was made to assign a share of this cost to cowpea grain storage.

Second, key estimates of the useful life of each storage technology were based on informed opinions from Purdue University and NCRE scientists and other key informants. Although these technologies may have some salvage value (which would reduce the total costs of the technology), the analysis assumes a zero salvage value because no data were available to estimate salvage value.

Third, the transportation cost of obtaining necessary inputs (e.g., plastic bags and sheets, earthenware cannaries) from the Maroua market were not included in the cost stream. Transport costs were set at zero because it was assumed that farmers generally would not make a special trip to the market to purchase the inputs required for each of the alternative technologies.

Fourth, cowpea grain was valued at the market price--not the farmgate price--since farmgate price data were not available.

Fifth, the opportunity cost of stored grain was set at zero in most of the analysis. The analysis of marketing structures and the question of whether marketing margins are high enough to cover the cost of storage were not part of the ROR section of the analysis. This assumption was later relaxed in an analysis of the farmers' "sell vs. store" decision.

Benefit Parameter Estimates

The benefits to the improved storage technologies are directly related to the level of storage losses farmers currently experience using traditional storage methods; as well as the level of storage loss reduction associated with each alternative improved technology. Since available data for estimating farmers' storage loss levels were only taken at one point in time, storage losses over time were estimated using a logistic function. Similarly, the estimates of storage loss levels using the improved technology are based on loss data collected at one point in time, and extrapolated over time using a logistic function.

Several benefits assumptions were also incorporated in the model. Estimates of household cowpea grain production, family size and their consumption rate (amount eaten per meal) were based on data collected by Wolfson (1990). It was assumed that all household production is pooled and household consumption is met from the pooled production[45].

[45]Each survey respondent reported key information about his/her cowpea enterprise and household characteristics. For large households, more than one household member may grow cowpeas. This assumption may underestimate the total level of household production (stock) available to a household.

6.2 Empirical Results: Rates of Return to Improved Storage

This analysis tested the profitability of adopting improved storage technology to both "traditional" and "advanced" farmers within the context of each's socioeconomic situation. The reported returns under the sensitivity analysis are generally sensitive to variations in the model parameters and differ from the base run.

Traditional Farmers' Situation

The benefit-cost analysis for "traditional" farmers' adopting the improved grain storage technologies was modeled to assess the possibility that by adopting the improved storage technology, low-income (and low cowpea production) households could profitably increase their security in consumption (i.e., extend own stocks).

The analysis showed that "traditional" farmers with initial cowpea grain inventories of only 82 kgs/household will consume their supply of cowpea after only four months. Consequently, they have little to gain from adopting improved storage technologies because during the early storage period (months 1-4) bruchid populations remain low. By the time bruchid damage is potentially severe, cowpea household inventories have already been exhausted.

In the base run for "traditional" farmers, the estimated returns to the three improved storage technologies are all negative, implying that the value of the grain "saved" is less than the cost of investing in the new technologies. All three of the improved technologies are dominated by (inferior to) the "traditional" farmers' existing storage technology.

In the sensitivity analysis for "traditional" farmers, the estimated returns to the three improved storage technologies remained dominated by the "traditional" farmers' existing storage technology.

Advanced Farmers' Situation

For "advanced" farmers, the benefit-cost analysis was modeled to evaluate the hypothesis that by adopting the improved storage technology, high-income (and high cowpea production) households could profitability either increase their security in consumption or sell surplus grain on speculation.

Improved Storage for Home Consumption

The analysis showed that "advanced" farmers with initial cowpea grain inventories of 287 kgs/household have sufficient grain to meet household consumption requirements for approximately six and one-half months, using their current storage technology. Thus, these farmers have much to gain from adopting the improved storage technologies because they still hold substantial inventories during later months when bruchid populations are potentially high and the likelihood for severe loss is great.

For "advanced" farmers who store all of their harvest for home consumption, all three estimated average returns to the improved technologies exceed the 50% minimum acceptable rate of return proposed by CIMMYT (1988). Thus, they all appear to be economically attractive for the "advanced" farmer[46]. But, the MRR analysis shows that compared to the farmers' current storage technology (sacks), only the returns to

[46]The ARR for adopting the improved ash, triple bagging and the solar heater in combination with triple bagging storage technologies was 177, 166 and 90%, respectively.

improved ash storage are very attractive[47]. Once the "advanced" farmer reduces his/her losses by adopting the improved ash storage, the additional return to adopting the more costly alternative is not sufficient to cover the added cost of adopting either the triple bag or the solar heater with triple bag technology.

In the sensitivity analysis for "advanced" farmers, the average and marginal rates of return to the improved ash technology were affected by variations in all five key parameters of the model. The ARR and MRR to triple bagging were also sensitive to changes in the five parameters, yet triple bagging generally remained dominated by the improved ash technology. The solar heater with triple bagging remained dominated by the improved ash technology.

Improved Storage for Future Sale

In the future, research is likely to increase cowpea yields--resulting in a situation where farmers may have available surpluses for future sale (speculation).

These "advanced" farmers with surplus grain available for future sale may benefit from improved storage, since experiments show high levels of bruchid damage after several months of storage. Consequently, farmers wanting to hold grain inventories for six or more months (until the price peaks) face potentially large storage losses.

In the base run, the benefit-cost model showed that for "advanced" farmers with surpluses (200 kg for sale after 9 months of storage), all three improved storage technologies generated high ARRs. Although all three technologies generated attractive ARRs, the marginal ROR analysis demonstrated that although adoption of triple bagging

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[47]The estimated MRR to improved ash storage over the "advanced" farmers' technology was 265%.

is financially promising (i.e., MRR of 124%), adoption of the solar heater (in combination with triple bags) is not profitable because it does not generate additional benefits above triple bagging alone.

In the sensitivity analysis for "advanced" farmers using improved storage for speculative purposes, the average and marginal rates of return to the improved ash technology were affected by variations in all six key parameters of the model. The ARR and MRR to triple bagging were also sensitive to changes in the six parameters, yet triple bagging generally remained dominated by the improved ash technology. The solar heater with triple bagging remained dominated by the improved ash technology.

Sell Now or Store and Sell Later

Holding stocks for future sale involves risk. For example, market price increases may not cover storage costs or the farmer's inventory may be unexpectedly damaged--rendering the grain unfit for sale. By selling at harvest, the farmer transfers this risk to traders, who are generally more financially able to bear risk.

Also, by holding stocks for future sale, farmers forego the opportunity of obtaining cash to meet immediate cash needs. Thus, they may have to borrow money (usually at high informal market rates) to pay outstanding debts and cover immediate household needs.

If the opportunity cost of the farmer's stored grain is taken into account, for on-farm storage for speculation to be profitable, the future market price received by the farmer must greatly exceed the price at harvest. This is because in addition to covering storage costs, the price rise must compensate the farmer for his/her investment in stored grain and associated risk. These analyses show that if a 3% per month opportunity cost is assigned to the value of the stored grain, it is more profitable for the farmer to sell at harvest than to store for speculation. If a 1.5% per month opportunity cost is assigned to the value of the stored grain, it is profitable to invest in the improved ash technology and store for 9 months (until the market price peaks).

6.3 Limitations, Policy Implications and Research Needs

Limitations

The limitations of this study are due to the assumptions required to compensate for the non-availability of various data. The benefit-cost analysis used a storage loss logistic function model to estimate rates of storage losses throughout the storage period/season. The model estimates household storage loss based on loss data collected in March 1990 and extrapolated to project monthly future losses. The availability of actual monthly storage loss estimates would have strengthened this analysis.

The core MRR and ARR analyses did not incorporate the opportunity cost of stored grain into the cost stream. In the MRR analysis, only the costs that vary across treatments are included in the cost stream, therefore the opportunity cost of stored grain was not included. In the ARR analysis, the opportunity cost of stored grain was also not included because the objective of the analysis was to determine the economic feasibility of adopting improved storage technologies and did not intend to determine whether marketing margins are high enough to cover the cost of on-farm storage. Rather, the impact of the opportunity cost of grain was considered separate in a "sell or store" analysis.

Finally, the system-wide effect on cowpea grain prices due to lower storage losses was not determined. Since, the cowpea market in northern Cameroon has traditionally been thin (i.e., small share of production marketed), wide-spread adoption of improved storage substantially reduce out seasonal price variations and thus, the returns to grain storage, especially for speculation.

Policy Implications

The rates of return were estimated for specific sets of investments and resulting benefits to both "advanced" and "traditional" cowpea farmers. The implications of these results vary by farmer type.

Farmers classified as "traditional" produce an average of less than 100 kg of cowpea grain and do not follow any of the recommended improved production/management practices (i.e., monocropping improved varieties and using 2-3 applications of insecticide). These farmers who cultivate 0.7 hectares of cowpeas, produce primarily for home consumption. Generally, they do not incur high levels of storage losses because their stocks are depleted before bruchid populations reach highly damaging levels. Farmers under these circumstances would not benefit from adopting improved storage.

Farmers classified as "advanced" produce an average of approximately 300 kg of cowpea grain, partly because they adopt the recommended practices (i.e., monocropping improved varieties and using 2-3 applications of insecticide) and because they plant a larger area to cowpeas (mean = 1.3 hectares). "Advanced" farmers who produce primarily for home consumption would benefit from adopting the improved ash storage, but not triple bagging or solar heater with triple bagging. On the other hand, "advanced" farmers who produce surpluses for future sale would benefit from adopting either the improve ash or triple bagging storage, but not solar heater with triple bagging.

When the opportunity cost of the farmer's stored grain is valued at 3% per month, it is more profitable for the farmer to sell at harvest rather than store for speculation. When the opportunity cost of the farmer's stored grain is valued at 1.5% per month, investment in the improved ash technology and storing until the market price peaks (historically in August) is profitable.

Research Needs

A farmer's storage decisions depend on his/her overall household food security strategy. The strategy a household adopts will depend on numerous factors including resources available to the farmer (i.e., land, labor, and/or capital), access to marketing and price information, household consumption needs, credit availability, and non-farm employment opportunities. Clearly, the farmer's decision/strategy is based on an interaction among these factors and not one factor alone. Furthermore, recognizing the differences among farmers' circumstances, desires and needs accurate and representative farm-level data are needed to help researchers and extension agents assess a technology's potential and constraints faced by farmers in making their technology choice decisions; as well as setting research priorities within a broader socioeconomic framework.

Research designed to address farmers' storage needs must be based on a clear understanding of how farmers allocate their production between consumption, storage, sales and other uses/disposal. In addition, understanding farmers' marketing patterns, the basic market infrastructure and market information is imperative so as to inform researchers/scientists about the potential demand for improved on-farm and/or off-farm storage. The following list is provided as a guide for project managers and researchers as to the minimum data needed to assess the socioeconomic feasibility of grain storage technology.

Total Availability of Cowpea Grain

- Data are needed to estimate total household cowpea availability, including the amount of grain supplied by all household members, from all fields managed by the household. In addition, plot level data on the gender of the plot manager is needed to determine who makes input and management decisions and who controls the production (in terms of its use for home consumption and/or sales). These data are required to generate a better understanding of the roll of cowpeas in the farming system.

Household Consumption and Utilization

- Accurate estimates of household consumption data (kg actually consumed/household/week and seasonal variations in consumption) are needed to calculate the rate at which grain is drawn-down; and to determine the contribution of cowpeas to household nutrition.

Storage Losses Over Time

- Accurate estimates of the current level of farmers' losses is critical to evaluating the potential of improved storage technologies. Data should be collected to assess the monthly storage losses associated with each alternative storage technology by sampling each month grain stored by farmers using each of the storage methods[48]--including grain stored for home consumption vs grain stored for sale, etc.

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[48]Including both the traditional and improved/new storage technologies.

Sales Pattern

• Household sales (commercialization) while, little is known about households' current selling behavior, whether the crop is grown for home use or sale will greatly affect the household's willingness to adopt new technology. Data are needed to determine when cowpeas are sold, the amount sold (kg of grain/leaves/pods), to whom (local market by farmer, middleman), the price received (farm gate vs. market), and how the farmer is paid (cash, in-kind). For example, Wolfson observed that if men control commercialization, it is usually sold in large (50 kg) lots, but if women control commercialization, it is usually sold in small allotments. A better understanding of these issues is relevant in determining a technology's potential. For example, if the grain storage needs of women are to be met--and they sell in small lots over the season--then triple bagging may not be appropriate for them because its effectiveness if decreased by repeatedly opening and closing the plastic bags.

Input and Output Prices

• Accurate input and output prices are critical to estimating the benefits and costs of an improved technology. Because prices vary across space and over time, data must be collected on prices farmers actually pay for inputs and the prices they actually receive for their crop (farmgate price).

Off-Farm Storage

The Cameroon research has focused on reducing on-farmers storage losses. But participants further along the marketing channel (i.e., middlemen, traders) may benefit even more than farmers from adopting improved storage technology if, as it appears to be the case, most of the cowpea crop is sold at harvest and stored for speculation by these market intermediaries. Data are needed to determine where in the marketing system the storage function is being performed--including the middleman's share of total storage, grain stock turnover, storage losses, and methods practiced to reduce loss. This information could by obtained by a market survey/study. Potentially, the improved grain storage technologies developed by the Bean/Cowpea CRSP scientists may greatly benefit off-farm storage users (i.e., middlemen and traders) and ultimately consumers. Because they likely store large volumes of grain for extended periods, the potential for loss is great. Under such circumstanced improved ash storage is not feasible but both the triple bag and solar heater are likely to be an economically viable storage investment.

Overall these results indicate the profitability of the improved storage technologies will depend on the level of losses farmers currently incur, the level of protection provided by the new technologies, the cost of adopting the improved technologies and the market price.

In designing their overall research strategy, the Bean/Cowpea CRSP scientists have sought to both design improved storage technologies and introduce bruchid resistances into new varieties. While the improved technologies are likely to only benefit a small share of the cowpea producers, the development of improved bruchid resistant varieties will have a much wider impact. Once introduced, bruchid resistant varieties will reduce losses--regardless of the farmers' current storage technology. Furthermore, all cowpea farmers will benefit from this technology, at no additional cost other than purchasing the resistant seed. In addition, the introduction of bruchid resistance will continue to provide protection against bruchid losses once cowpeas are marketed. In the long run, reduced losses will benefit consumers as these gains are translated into lower retail cowpea prices.

Table A1 Sensitivity Analysis: "Traditional" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 1, Household Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	8.0	0.55	9.7	2.2	9.7	2.2
Partial Budget (CFA)								
Gross Benefits[h]	0	0	904	62	1,096	249	1,096	249
Total Costs[i]	0	0	3,478	3,478	1,043	1,043	1,901	1,901
Annual Costs[j]	0	0	696	696	1,043	1,043	1,472	1,472
Net Benefits (gross benefits minus annual costs)	NA	NA	208	-634	53	-794	-376	-1,223
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	208	0	0	0	0	0
Additional Annual Costs	NA	NA	696	696	347	347	429	429
Rate of Returns (%)								
Average	NA	NA	30	-91.1	5.1	-76.1	-25.5	-83.1
Marginal	NA	NA	30	D	D	D	D	D

[a]82 kg of cowpea grain stored under non-adopter farmer situation.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 5 months (November-March).
[j]Total costs/useful life of the technology.

Table A2 Sensitivity Analysis: "Traditional" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 2, Improved Technology Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	3.46	5.24	5.62	6.51	5.62	6.51
Partial Budget (CFA)								
Gross Benefits[h]	0	0	391	592	635	736	635	736
Total Costs[i]	0	0	3,478	3,478	1,043	1,043	1,901	1,901
Annual Costs[j]	0	0	696	696	1,043	1,043	1,472	1,472
Net Benefits (gross benefits minus annual costs)	NA	NA	-305	-104	-408	-307	-837	-736
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	0	0	0	0	0	0
Additional Annual Costs	NA	NA	696	696	347	347	429	429
Rate of Returns (%)								
Average	NA	NA	-43.8	-14.9	-39.1	-29.4	-56.9	-50.0
Marginal	NA	NA	D	D	D	D	D	D

[a]82 kg of cowpea grain stored under non-adopter farmer situation.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 5 months (November-March).
[j]Total costs/useful life of the technology.

Table A3 Sensitivity Analysis: "Traditional" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 3, Input Cost +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0	0	4.4	4.4	6.1	6.1	6.1	6.1
Partial Budget (CFA)								
Gross Benefits[h]	0	0	497	497	689	689	689	689
Total Costs[i]	0	0	4,347	2,608	1,304	783	2,377	1,426
Annual Costs[j]	0	0	869	522	1,304	783	1,840	1,104
Net Benefits (gross benefits minus annual costs)	NA	NA	-372	-25	-615	-94	-1,151	-415
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	0	0	0	0	0	0
Additional Annual Costs	NA	NA	869	522	435	261	536	321
Rate of Returns (%)								
Average	NA	NA	-42.8	-4.8	-47.2	-12.0	-62.6	-37.6
Marginal	NA	NA	D	D	D	D	D	D

[a]82 kg of cowpea grain stored under non-adopter farmer situation.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 5 months (November-March).
[j]Total costs/useful life of the technology.

Table A4 Sensitivity Analysis: "Traditional" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 4, Market Price of Cowpea Grain +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0	0	4.4	4.4	6.1	6.1	6.1	6.1
Partial Budget (CFA)								
Gross Benefits[h]	0	0	622	373	862	517	862	517
Total Costs[i]	0	0	3,478	3,478	1,043	1,043	1,901	1,901
Annual Costs[j]	0	0	696	696	1,043	1,043	1,472	1,472
Net Benefits (gross benefits minus annual costs)	NA	NA	-74	-323	-181	-526	-610	-955
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	0	0	0	0	0	0
Additional Annual Costs	NA	NA	696	696	347	347	429	429
Rate of Returns (%)								
Average	NA	NA	-10.6	-46.4	-17.4	-50.4	-41.4	-64.9
Marginal	NA	NA	D	D	D	D	D	D

[a]82 kg of cowpea grain stored under non-adopter farmer situation.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 5 months (November-March).
[j]Total costs/useful life of the technology.

Table A5 Sensitivity Analysis: "Traditional" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 5, Opportunity Cost of Capital/Interest Rate +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	4.4	4.4	6.1	6.1	6.1	6.1
Partial Budget (CFA)								
Gross Benefits[h]	0	0	497	497	689	689	689	689
Total Costs[i]	0	0	3,739	3,232	1,122	970	2,044	1,767
Annual Costs[j]	0	0	748	646	1,122	970	1,583	1,368
Net Benefits (gross benefits minus annual costs)	NA	NA	-251	-149	-443	-281	-894	-679
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	0	0	0	0	0	0
Additional Annual Costs	NA	NA	748	646	374	324	461	398
Rate of Returns (%)								
Average	NA	NA	-33.6	-23.1	-39.5	-29.0	-56.5	-49.6
Marginal	NA	NA	D	D	D	D	D	D

[a]82 kg of cowpea grain stored under non-adopter farmer situation.
[b]Granary.
[c]2 cannaries.
[d]6 plastic bags.
[e]1 solar heater shared by 10 households plus 6 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 5 (March) market price of 113 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 5 months (November-March).
[j]Total costs/useful life of the technology.

Table A6 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 1, Household Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	69.7	44.8	78.7	53.8	78.7	53.8
Partial Budget (CFA)								
Gross Benefits	0	0	8,155[h]	7,661[i]	9,208[h]	9,200[i]	9,208[h]	9,200[i]
Total Costs	2,214[j]	2,280[k]	11,069[j]	11,401[k]	3,321[j]	3,420[k]	4,231[j]	4,358[k]
Annual Costs[l]	738	760	2,214	2,280	3,321	3,420	3,776	3,889
Net Benefits (gross benefits minus annual costs)	NA	NA	5,941	5,381	5,887	5,780	5,432	5,311
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	5,941	5,381	0	399	0	0
Additional Annual Costs	NA	NA	1,476	1,520	1,107	1,140	455	469
Rate of Returns (%)								
Average	NA	NA	268	236	177	169	144	137
Marginal	NA	NA	403	354	D	35	D	D

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Cowpea grain (kg) "saved" valued at month 8 (June) market price of 171 CFA.
[j]Includes opportunity cost of capital (3% per month) for 7 months.
[k]Includes opportunity cost of capital (3% per month) for 8 months.
[l]Total costs/useful life of the technology.

Table A7 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 2, Improved Technology Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	48.6	56.04	49.5	63.2	49.5	63.2
Partial Budget (CFA)								
Gross Benefits[h]	0	0	5,686	6,557	5,792	7,394	5,792	7,394
Total Costs[i]	2,214	2,214	11,069	11,069	3,321	3,321	4,231	4,231
Annual Costs[j]	738	738	2,214	2,214	3,321	3,321	3,776	3,776
Net Benefits (gross benefits minus annual costs)	NA	NA	3,472	4,343	2,471	4,073	2,016	3,618
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	3,472	4,343	0	0	0	0
Additional Annual Costs	NA	NA	1,476	1,476	1,107	1,107	455	455
Rate of Returns (%)								
Average	NA	NA	157	196	74	123	53	96
Marginal	NA	NA	235	294	D	D	D	D

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Includes opportunity cost of capital (3% per month) for 7 months (November-May).
[j]Total costs/useful life of the technology.

Table A8 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 3, Input Cost +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0	0	52.4	52.4	61.3	61.3	61.3	61.3
Partial Budget (CFA)								
Gross Benefits[h]	0	0	6,131	6,131	7,172	7,172	7,172	7,172
Total Costs[i]	2,767	1,660	13,836	8,302	4,151	2,490	15,527	3,173
Annual Costs[j]	922	553	2,767	1,660	4,151	2,490	9,839	2,832
Net Benefits (gross benefits minus annual costs)	NA	NA	3,364	4,471	3,021	4,682	-2,667	4,340
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	3,364	4,471	0	211	0	0
Additional Annual Costs	NA	NA	1,845	1,107	1,384	830	5,688	342
Rate of Returns (%)								
Average	NA	NA	122	269	73	188	-27	153
Marginal	NA	NA	182	404	D	25	D	D

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Includes opportunity cost of capital (3% per month) for 7 months (November-May).
[j]Total costs/useful life of the technology.

Table A9 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 4 Market Price of Cowpea Grain +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0	0	52.4	52.4	61.3	61.3	61.3	61.3
Partial Budget (CFA)								
Gross Benefits[h]	0	0	7,664	4,598	8,965	5,379	8,965	5,379
Total Costs[i]	2,214	2,214	11,069	11,069	3,321	3,321	4,231	4,231
Annual Costs[j]	738	738	2,214	2,214	3,321	3,321	3,776	3,776
Net Benefits (gross benefits minus annual costs)	NA	NA	5,450	2,384	5,644	2,058	5,189	1,603
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	5,450	2,384	194	0	0	0
Additional Annual Costs	NA	NA	1,476	1,476	1,107	1,107	455	455
Rate of Returns (%)								
Average	NA	NA	246	108	170	62	137	42
Marginal	NA	NA	369	162	18	D	D	D

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Includes opportunity cost of capital (3% per month) for 7 months (November-May).
[j]Total costs/useful life of the technology.

Table A10 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 5 Opportunity Cost of Capital/Interest Rate +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0	0	52.4	52.4	61.3	61.3	61.3	61.3
Partial Budget (CFA)								
Gross Benefits[h]	0	0	6,131	6,131	7,172	7,172	7,172	7,172
Total Costs[i]	2,450	1,998	12,248	9,989	3,674	2,997	4,681	3,818
Annual Costs[j]	817	666	2,450	1,998	3,674	2,997	4,178	3,407
Net Benefits (gross benefits minus annual costs)	NA	NA	3,681	4,133	3,498	4,175	2,994	3,765
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	3,681	4,133	0	42	0	0
Additional Annual Costs	NA	NA	1,633	1,332	1,224	999	504	410
Rate of Returns (%)								
Average	NA	NA	150	207	952	139	72	111
Marginal	NA	NA	225	310	D	4.2	D	D

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Includes opportunity cost of capital (3% per month) for 7 months (November-May).
[j]Total costs/useful life of the technology.

Table A11 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Home Consumption[a]; Run 6, Solar Heater with Triple Bag Technology 100% Protection.

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved[g] (kg)	0	52.4	61.3	79.5
Partial Budget (CFA)	0	6,131	7,172	9,302
Gross Benefits[h]				
Total Costs[i]	2,214	11,069	3,321	4,231
Annual Costs[j]	738	2,214	3,321	3,776
Net Benefits (gross benefits minus annual costs)	NA	3,917	3,851	5,526
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	3,917	0	1,675
Additional Annual Costs	NA	1,476	1,107	455
Rate of Returns (%)				
Average	NA	177	116	146
Marginal	NA	265	D	368

[a]287 kg of cowpea grain stored under advanced adopter farmer situation.
[b]6 cloth sacks.
[c]6 cannaries.
[d]18 plastic bags.
[e]1 solar heater shared by 10 households plus 18 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 7 (May) market price of 117 CFA.
[i]Includes opportunity cost of capital (3% per month) for 7 months (November-May).
[j]Total costs/useful life of the technology.

Table A12 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 1, Household Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0.15	4.1	181.4	177.4	190.6	186.6	190.6	186.6
Partial Budget (CFA)								
Gross Benefits[h]	29	804	35,554	34,770	37,358	36,574	37,358	36,574
Total Costs[i]	1,613	1,613	8,063	8,063	2,419	2,419	3,414	3,414
Annual Costs[j]	538	538	1,613	1,613	2,419	2,419	2,916	2,916
Net Benefits (gross benefits minus annual costs)	-509	266	33,941	33,157	34,939	34,155	34,442	33,658
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	34,450	32,891	998	998	-497	-497
Additional Annual Costs	NA	NA	1,075	1,075	806	806	497	497
Rate of Returns (%)								
Average	-95	49	2,104	2,056	1,444	1,412	1,181	1,154
Marginal	NA	NA	3,205	3,060	124	124	D	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

Table A13 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 2, Improved Technology Losses +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0.6	0.6	177.5	184.2	186.7	191.8	186.7	191.8
Partial Budget (CFA)								
Gross Benefits[h]	118	118	34,790	36,103	36,593	37,593	36,593	37,593
Total Costs[i]	1,613	1,613	8,063	8,063	2,419	2,419	3,414	3,414
Annual Use Costs[j]	538	538	1,613	1,613	2,419	2,419	2,916	2,916
Net Benefits (gross benefits minus annual costs)	-420	-420	33,177	34,490	34,174	35,174	33,677	34,677
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	33,597	34,910	997	684	-497	-497
Additional Annual Costs	NA	NA	1,075	1,075	806	806	497	497
Rate of Returns (%)								
Average	-78	-78	2,057	2,138	1,413	1,454	1,155	1,189
Marginal	NA	NA	3,125	3,247	124	85	D	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

Table A14 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 3, Input Cost +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0.6	0.6	180.9	180.9	190.1	190.1	190.1	190.1
Partial Budget (CFA)								
Gross Benefits[h]	118	118	35,456	35,456	37,260	37,260	37,260	37,260
Total Costs[i]	2,016	1,210	10,079	6,048	3,024	1,814	4,267	2,560
Annual Costs[j]	652	403	2,016	1,210	3,024	1,814	3,645	2,187
Net Benefits (gross benefits minus annual costs)	-534	-285	33,440	34,246	34,236	35,446	33,615	35,073
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	33,974	34,531	796	1,200	-621	-373
Additional Annual Costs	NA	NA	1,364	807	1,008	604	621	373
Rate of Returns (%)								
Average	-82	-71	1,659	2,830	1,132	1,954	922	1,604
Marginal	NA	NA	2,491	4,279	79	199	D	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

Table A15 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 4 Market Price of Cowpea Grain +/- 25%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 25%	b - 25%	b + 25%	b - 25%	b+ 25%	b - 25%	b + 25%	b - 25%
Grain Saved[g] (kg)	0.6	0.6	180.9	180.9	190.1	190.1	190.1	190.1
Partial Budget (CFA)								
Gross Benefits[h]	147	88	44,321	26,592	46,575	27,945	46,575	27,945
Total Costs[i]	1,613	1,613	8,063	8,063	2,419	2,419	3,414	3,414
Annual Costs[j]	538	538	1,613	1,613	2,419	2,419	2,916	2,916
Net Benefits (gross benefits minus annual costs)	-391	-450	42,708	24,979	44,156	25,526	43,659	25,029
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	43,099	25,429	1,448	547	-497	-497
Additional Annual Costs	NA	NA	1,075	1,075	806	806	497	497
Rate of Returns (%)								
Average	-73	-84	2,648	1,549	1,825	1,055	1,497	858
Marginal	NA	NA	4,009	2,365	180	68	D	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

Table A16 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 5 Opportunity Cost of Capital/Interest Rate +/- 50%.

	Farmers' Current Practice[b]		Improved Ash Storage[c]		Triple Bag Storage[d]		Solar Heater & Triple Bag Storage[e]	
	b[f] + 50%	b - 50%	b + 50%	b - 50%	b+ 50%	b - 50%	b + 50%	b - 50%
Grain Saved[g] (kg)	0.6	0.6	180.9	180.9	190.1	190.1	190.1	190.1
Partial Budget (CFA)								
Gross Benefits[h]	118	118	35,456	35,456	37,260	37,260	37,260	37,260
Total Costs[i]	1,864	1,393	9,318	6,963	2,795	2,089	3,945	2,948
Annual Costs[j]	621	464	1,864	1,393	2,795	2,089	3,370	2,518
Net Benefits (gross benefits minus annual costs)	-503	-346	33,592	34,063	34,465	35,171	33,890	34,742
Marginal Benefits and Costs (CFA)								
Additional Net Benefits	NA	NA	34,095	34,409	873	1,108	-575	-429
Additional Annual Costs	NA	NA	1,243	929	931	696	575	429
Rate of Returns (%)								
Average	-81	-75	1,802	2,445	1,233	1,684	1,006	1,380
Marginal	NA	NA	2,743	3,704	94	159	D	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]"b" represents base run values for the variable.
[g]Additional kg of cowpea grain as a result of using the improved technologies.
[h]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

Table A17 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 6, Solar Heater with Triple Bag Technology 100% Protection.

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved (kg)	0.6	180.9	190.1	200
Partial Budget[f] (CFA)				
Gross Benefits[g]	118	35,456	37,260	39,200
Total Costs[h]	1,613	8,063	2,419	3,414
Annual Costs[i]	538	1,613	2,419	2,916
Net Benefits (gross benefits minus annual costs)	-420	33,843	34,841	36,284
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	34,263	998	1,326
Additional Annual Costs	NA	1,075	806	497
Rate of Returns (%)				
Average	-78	2,098	1,440	1,244
Marginal	NA	3,187	124	267

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]Additional kg of cowpea grain as a result of using the improved technologies.
[g]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[h]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[i]Total costs/useful life of the technology.

Table A18 Sensitivity Analysis: "Advanced" Farmer Using Improved Cowpea Storage Technologies for Grain Intended for Future Sale[a]; Run 7, 20% Premium Paid for Improved Quality Grain.

	Farmers' Current Practice[b]	Improved Ash Storage[c]	Triple Bag Storage[d]	Solar Heater & Triple Bag Storage[e]
Grain Saved[f] (kg)	0.6	180.9	190.1	190.1
Partial Budget (CFA)				
Gross Benefits[g]	118	42,548[h]	44,712[h]	44,712[h]
Total Costs[i]	1,613	8,063	2,419	3,414
Annual Costs[j]	538	1,613	2,419	2,916
Net Benefits (gross benefits minus annual costs)	-420	40,935	42,293	41,796
Marginal Benefits and Costs (CFA)				
Additional Net Benefits	NA	41,355	1,358	-497
Additional Annual Costs	NA	1,075	806	497
Rate of Returns (%)				
Average	-78	2,538	1,748	1,433
Marginal	NA	3,847	168	D

[a]200 kg of cowpea grain stored under advanced adopter farmer situation.
[b]4 cloth sacks.
[c]4 cannaries.
[d]12 plastic bags.
[e]1 solar heater shared by 10 households plus 12 plastic bags.
[f]Additional kg of cowpea grain as a result of using the improved technologies.
[g]Cowpea grain (kg) "saved" valued at month 10 (August) market price of 196 CFA/kg.
[h]Cowpea grain (kg) "saved" valued at 20% premium month 10 (August) market price of 235.2 CFA/kg.
[i]Includes opportunity cost of capital (3% per month) for 10 months (November-August).
[j]Total costs/useful life of the technology.

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