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By Hayatullah Ahmadzai

Entitled On-Farm Grain Storage Losses: Potential Gains from Improved Storage Facility and Management Practices in Afghanistan

For the degree of Master of Science

Is approved by the final examining committee:

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ON-FARM GRAIN STORAGE LOSSES: POTENTIAL GAINS FROM IMPROVED STORAGE FACILITY AND MANAGEMENT PRACTICES IN AFGHANISTAN

A Thesis

Submitted to the Faculty

of

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by

Hayatullah Ahmadzai

In Partial Fulfillment of the

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of

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For my father Fazal Mohammad Ahmadzai, your unconditional love, encouragement and support has given me the opportunity to pursue my goals.

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ABSTRACT

Ahmadzai, Hayatullah. M.S., Purdue University, May 2011. On-Farm Grain Storage Losses: Potential Gains from Improved Storage Facility and Management Practices in Afghanistan. Major Professor: Roman Keeney.

Improving grain storage is a key element in improving food security policies which seeks to stimulate production, facilitate distribution, and ease crisis management. In this study we develop a conceptual model to investigate farm household storage management in Afghanistan. Our representative household approach makes explicit assumptions about family needs for food security in the current and future periods by considering monthly food consumption as well as reserve holding for seed in the next season's crop.

With limited farm level data we make a number of assumptions about status quo storage practice in the representative household, identifying the potential gains in food security that can be made with reasonable management interventions. We develop a framework to estimate the amount of grain a representative farm household must annually place in storage to meet household consumption and planting needs accounting for storage loss over the course of the 12 month storage period. The twelve-period model allows us to link farm storage to a model of insect population growth to

consider the economic impact of a representative pest type and the cost and returns of management practices which reduce losses associated with this pest.

The model is used to estimate the grain savings and impact on household food security attributable to a specific management practice that reduces insect population. The model in this study provides a solid framework for future directions concerning potential gains from improved storage facility and management practices. One of the most important finding from the sensitivity of the model is that increasing mortality rate is the most efficient way to reduce storage losses due to insects.

CHAPTER 1. INTRODUCTION

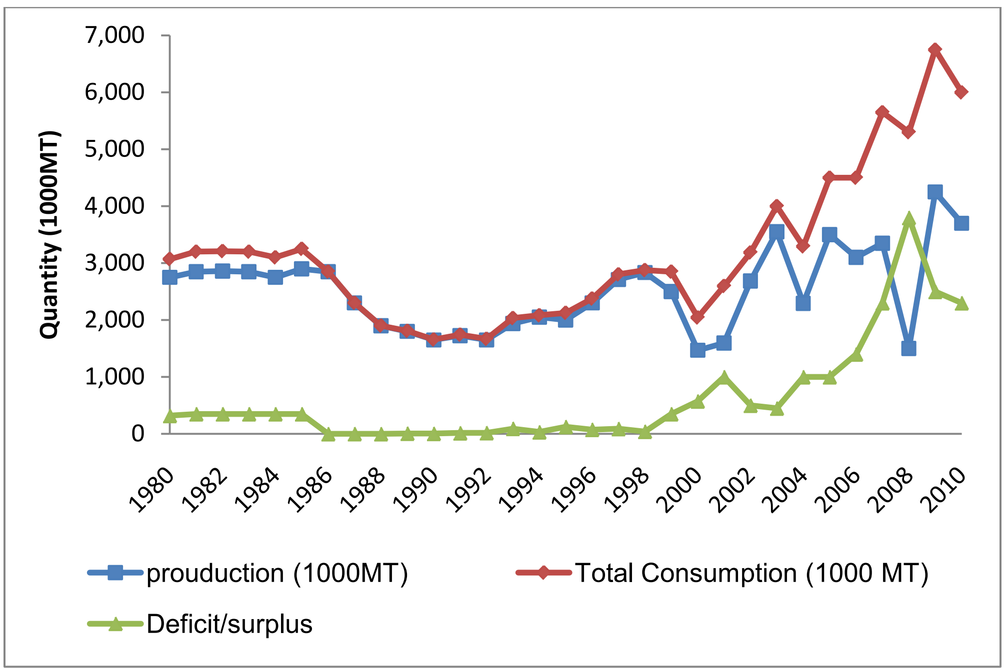
1.1. Overview

Afghanistan is an arid, mountainous, landlocked country in South-Central Asia ranking among the world's poorest and least developed. More than two decades of war and political instability and severe and persistent drought conditions in the 1990s pushed Afghanistan's economy to the verge of collapse with its people almost entirely dependent on foreign aid in the early part of the 21st century (ADO, 2002).

Re-development efforts in Afghanistan began with the establishment of transitional government in 2001 largely driven by an infusion of international assistance, the recovery of the agricultural sector, and service sector growth. The CIA FACTBOOK reports national income (GDP) of 14.04 billion ($US) in 2009 ($800 on a per capita basis). Agriculture is the main source of income in the country employing almost 80% of the labor force (CIA, 2010). The international community and the Afghan government have made the agricultural sector an explicit focus of economic development programs in Afghanistan. Per World Bank statistics, GDP growth in the country for fiscal years 2009 and 2010 is estimated at 22.5%, with agriculture accounting for 53% of that amount. This agriculture led growth was driven by strong wheat production which nearly doubled (5 million metric tons) the preceding five year average output (3.4 million metric tons) (World Bank, 2010). Despite this income growth at the national level, more than half of the population remains below the poverty line leaving the country in a humanitarian crisis, which includes events that represent a critical threat to the health, safety, security or wellbeing of a community, (WFP, 2009). The National Risk and Vulnerability Assessment (NRVA) conducted by the Ministry of Rural Rehabilitation and Development (MRRD) of Afghanistan and the central statistics office (CSO) in 2005 is one recent source with extensive information on national food security. This study identified approximately 61 percent of Afghans from the rural, urban, and Kuchi (unsettled pastoralists) with low dietary diversity and classified their food consumption level as poor to very poor. Approximately 8.5 million Afghans throughout the country (~30 percent of the population) do not meet minimum food requirements and exhibit some degree of food insecurity. Twenty percent of the population suffers from chronic food insecurity concentrated in the Central Highlands (MMRD and CSO, 2005).

Sixty percent of calorie intake comes from wheat in the Afghan diet. The average Afghan consumes ~186 kg of wheat over the course of a year. Grains, especially wheat, are considered the most important crop in the food security programs (Chabot and Dorosh, 2006). Afghanistan suffers from a shortage of food in general and in particular a shortage of grains forcing the population to consume less and eat low quality grain. Wheat production in the country currently falls short of self sufficiency requirements. Although the production reported in the graph ignores post-harvest losses, Afghanistan was almost self sufficient prior to1998 as shown in Figure1-1 (FAS-USDA, 2010).

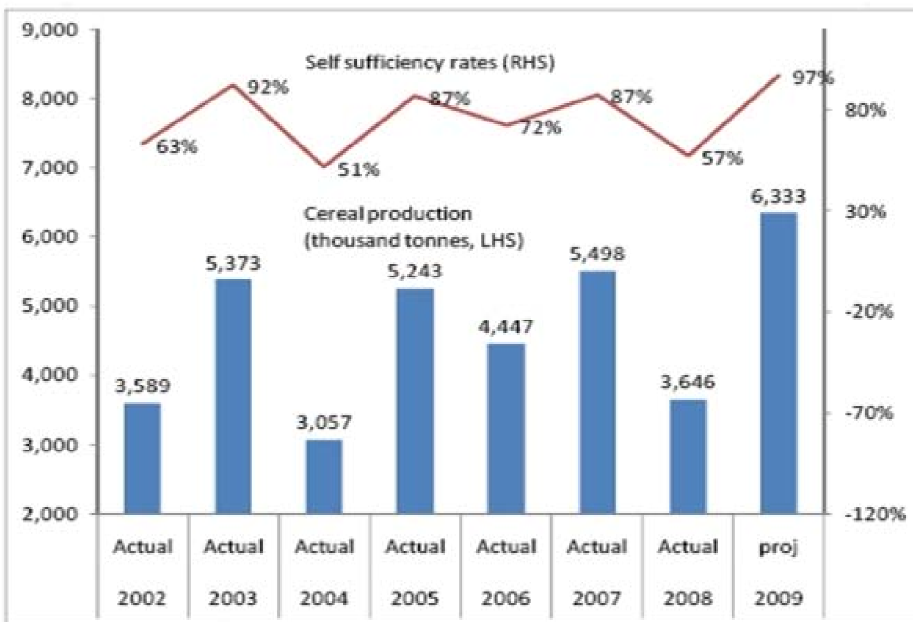
Drought which started in the mid 1990s and war resulted in declines in wheat production which has led to food insecure conditions. However, in the graph we see that in 2009 and 2010 production and consumption are higher than ever before, which can be explained by two factors. First, as the return of Afghan immigrants after 2001 started, the consumption as well as the production increased. Second, increase in consumption and production after 2001 might be due to the recent growth in GDP per capita.



Source: Foreign Agriculture Service (FAS) of the USDA

Figure 1-1: Domestic Production, Consumption and Deficit/Surplus of Wheat in Afghanistan

To achieve wheat self sufficiency, Afghanistan would have to increase the domestically produced wheat. Given the average consumption rate as in the previous figure, figure1-2 provides information on domestic cereal production and self-sufficiency rates from 2002-2009. The self-sufficiency rate in each year is determined by domestic cereal production, imports, and international cereal aid. The gap between domestic cereal production and self-sufficiency gives us an idea that Afghanistan has to increase its domestic grain (mainly wheat) production to achieve self-sufficiency.



Source: Ministry of Agriculture, World Bank staff

Figure 1-2: Domestic Cereal Production and Self-Sufficiency Rates in Afghanistan

Another route for increasing the sufficiency ratio of Afghan wheat production is reducing the post-harvest losses common in developing countries with limited technology for storage. Post-harvest losses are attributed to a combination of factors ranging from the methods used in crop harvesting, drying, storing, and milling. Recent technological development including improved seeds, fertilizer, and farm practices have resulted in promising yield increases for irrigated crops. But the marketing mechanism, along with the transport, storage and other related facilities are not yet adequate to cope with the significant production increases in Afghanistan where only the most basic (e.g. non-hermetic binning or bagging) technologies are used.

Post harvest losses have been estimated at 20% of total wheat production in Afghanistan (USAID Afghanistan, 2009). Examining the potential for reducing 20% (almost 50 million metric tons) of wheat production that is damaged or wasted between harvest and consumption provides the rationale for the research conducted and reported in this thesis. Improved storage can enhance food security and improve health by increasing the quantity and maintaining quality of the grain available for household consumption. In this study, we present a traditional Afghan grain storage system and management practices, and discusses a number of factors associated with post-harvest losses and quality deteriorations. When we move to our model based analysis, we narrow our focus to the problem of insect infestation as this has proven to be an area of research with high practical impact in other developed country (Murdock,seck and Ntoukam, 2003).

The analysis reported here makes use of a model describing the linkages between household grain storage and household level food security. A representative farm household faced with post-harvest losses must plan consumption of grain over the course of a year while maintaining a supply of seed for the next crop and dealing with an increasing pest population as the initial infestation grows according to insect response to seasonal climate change.

1.2. Research Problem, Objectives, and Scope

Imperfect and missing grain markets in a region characterized by high post-harvest losses necessitate research quantifying the potential gains of investment in education and technology for on-farm grain storage. The success of a farming enterprise (e.g. profitability for cash crops or food security for self-sufficient crops) can be significantly impacted by decisions made by the producer in the post–harvest period. Given Afghanistan's consistently high post-harvest losses, grain storage and management stand as a critical issue in addressing nation food security initiatives.

In the absence of better management practices and construction of efficient storage facilities, Afghanistan faces a continuous threat of food insecure conditions. The present population of around 30 million people and the rapid increase in population needs doubling (30million people x per capita wheat consumption of 162 kg – current national production of 3 million metric tons = 2millon metric tons) the present production of grain, particularly wheat to meet the amount of food demanded (Malletta, 2006)

Developments to achieve yield and land in crops will necessarily be required as part of a long run program to expand the agricultural sector but increased output will only exacerbate the post-harvest loss problem without a program for improving storage efficiency. Research and findings by the Ministry of Agriculture, irrigation and Livestock (MAIL) and Food and Agriculture Organization of the United Nations (FAO), a 3% reducing post-harvest losses will lead to the availability of (75,000 to 100,000M) tons of grain to people in Afghanistan (MAIL and FAO, 2008). This national level statistic describes that reduction of post-harvest losses can significantly contribute to food security on household level as well. Given the fact that household grain storage facility and management practices are considerably primitive in the country, the potential for improvement is easily achievable if proper research and investment is done in this field.

Given that many Afghanistan households persist in food insecure conditions, the potential of reducing post-harvest losses provides an avenue with potential for immediate impact. Investment in research to improve grain storage and reduce post-harvest losses thus provides an excellent opportunity to develop an agenda for education and policy oriented toward improving household level welfare and advancing agricultural and economic development.

The primary objective of this study is to provide a consistent framework for analysis of the relationship between stored grain loss and household food security in Afghanistan. Though we present quantitative results from this model, it is essential to note that research and data is scarce. The absence of data, particularly data collected from household production, management, or consumption surveys is a considerable limitation for those quantitative results. Through sensitivity we are able to gain some insight into which results are most likely to be robust. Beyond the household data issue, the phenology model used to determine insect growth and its link to grain loss over the storage life of grain is based on wide range of assumptions similarly handled with sensitivity scenarios.

CHAPTER 2. BACKGROUND

2.1. Basic Concept of Grain Storage and Storage Systems

Grain storage practices have been of longstanding interest for the role they play in the transformation of harvested crops into stable food supply. In much of the world, the practices are still governed by historic traditions and climate circumstances that are particular to a region. Storage is the practice of keeping seed in store houses, heaps, bulks and bags in such a way that they retain both food and seedling value for future use. This is accomplished by managing conditions like ventilation, temperature and humidity (Payne, 2002).

Grain storage is an economic challenge because food is harvested in one season and consumed (or sold for income) over time to ensure a subsistence level of consumption. In developing countries like Afghanistan, rural household grain and in particular wheat, is the key staple and main consumption good. Households produce, store and purchase grain to ensure that they can meet their consumption needs in the face of many factors over which they have limited influence such as yield or market prices (USAID, 2006).

Grain storage occurs for reasons other than keeping the grain for the next season or next year. Grain maybe stored as household management response to the short term surplus of food at harvest time, insurances against periods of scarcity or famine, to prepare for special events and celebrations, or provide food to maintain a better balance in the diet through the year.

Storage plays a central role in the grain market. It allows for more consistent supply during the non-harvest seasons which enables goods to be made available to buyers whenever they are in demand and at the place of business where the customer needs them. Thus, grain storage is used to manage quantity demanded and price volatility that occurs due to seasonality. Storage performs the function of smoothing out irregularities in production. In the present age of competition, every producer tries to produce in anticipation of demand so as to provide steady supply in the market. Storage enables the society to face natural calamities such as floods, famine, drought, etc. In such emergencies, commodities can be made available from storage. Storage allows accumulation of stock to be transported in bulk quantities so as to reduce the transportation costs (Proctor, 1994).

Grain storage in Afghanistan usually takes place on farm and is mostly for a household or family consumption. These household storage facilities are very primitive and include mud structures mostly bin or pots, metal drums, bags, and floors of rooms and many other methods depending on the economic and climatic factors (see Appendix A and B).

Storage systems or structures in most developing countries in South Asia are somewhat the same. In neighboring country Pakistan, on farm storage systems are simple and similar to those used in Afghanistan. Pakistani farmers use mud bins, bags and straw structures with almost 70 percent of wheat stored on farms in plastic bags. The majority of the wheat in Afghanistan is stored the same way in plastic bags as well (Tunio, 2002).

2.2. <u>Role of Storage in the National Economy</u>

In Afghanistan wheat is the most important staple food. Wheat production is on an annual basis with a single harvest per year. In order to feed its population, most of the Afghan cereal production must be held in storage for a period ranging from months to years. This situation and the uncertainty of output from year to year, makes grain storage a vital component for managing grain supplies in Afghanistan. Moreover, uncertainties about trade relationships with neighboring countries and limited access to import markets make grain storage a priority concern for the Afghan government (Chabot and Dorosh, 2006). .

Like many developing countries, the Afghan market for food grains is characterized by broadly fluctuating supply with demand that is fairly stable throughout the year since consumption of basic foods such as grains does not vary greatly. Market supply depends on imports from neighboring countries as well as domestic production which fluctuates greatly with climatic conditions (especially the amount of rainfall due to Afghanistan’s arid climate). Demand in the food grain market is inelastic such that large changes in the market price lead to relatively small changes in the amount of grains purchased (Hector and Favre, 2003). Thus, a primary function of storage in an economy is to balance out fluctuations in market supply, by holding surplus output from one period and releasing it onto the market when supplies are short. This serves to smooth out quantity supplied and stabilize market prices.

Storage is a component within a farming system, a trading enterprise, or a government food management system, and may be undertaken because of its contribution to other activities or objectives within these broader contexts. Local storage practices play a vital part in the household food security. In order to alleviate immediate hunger and change the conditions under which hunger develops and persists, better household level on-farm storage management strategy is required to sustain supply and reduce post-harvest losses (WFP, 2006).

Farm storage is an important management consideration for Afghan farmers. For small farmers in most regions of this country**,** the motivation behind storing grains is to ensure household food supplies. Additionally, this stored grain provides a form of saving which may be used to cover future cash needs or as seed to conserve future input costs. Generally speaking, small farmers in Afghanistan only market their surplus grain at the time of harvest or slightly after harvesting season, therefore speculative storage is less likely to happen (FAO and MAIL, 2009). This is partially due to limited on-farm storage facilities and partially due to the small amount of surplus which is not considered worth storing.

Traders carry out inter-seasonal storage of coarse grains and flour. Although traders store a noteworthy amount of grain for commercial purposes in many countries, in Afghanistan most traders do not store grains for long periods due to the high costs and other issues associated with storage. Therefore they buy and sell quickly, earning a moderate profit on each transaction. Traders in Afghanistan primarily serve a transport function, moving grain from remote areas to more populated areas, from surplus areas to shortage areas, and imported grains.

Governments also store grain depending on how they wish to influence the grain market. A primary objective of developing countries governments is to stabilize prices and market quantities of basic foods leading to state managed or incentivized storage. This stabilization purpose of prices and quantities is achieved by the government through movement of wheat from surplus to deficit years, from surplus seasons to deficit seasons, and to ensure a smooth flow of supplies at all times. These features necessitate the government maintaining inter-annual stocks to move grain from surplus to deficit years, inter-seasonal stocks to move grain from surplus to deficit seasons and import buffer stocks to stabilize the supplies flow all the time (Proctor, 1994).

Food insecurity is a continuing problem in Afghanistan. Holding storage allows for some rationed distribution to combat famine in times of extraordinary shortage. The Afghanistan ministry of agriculture operates a strategic grain reserve program keeping 200,000 metric tons of wheat to assist more than two million people in times of crisis (MAIL, 2008).

In many developing countries including Afghanistan, grain storage is practiced by farmers, traders and governments to facilitate marketing and ensure food security. At present while the majority of grain is stored on the farm where households store for their own consumption needs the government is becoming more involved in storage, since the concern of national food security is fundamental to political stability ((Proctor, 1994).

2.3. Storage and Food Security Issues in Afghanistan

In the previous section it was argued that improved grain storage is critical for ensuring the domestic food supply. In this section, we examine the food security conditions in Afghanistan and explore the link between post-harvest grain storage and food security. Ensuring adequate availability of food and household food security is a major challenge for the Afghan government. Afghanistan now suffers from shortfalls after decades of continuous warfare and recurring drought. With yearly cereal demand of around 5 million tons and wheat production ranging from 2.3 to 4.5 million tons in recent years, the country has faced grain imports at increasing cost and heavy reliance on food aid (2010 World Bank). According to the United Nations World Food Program (WFP) there were 7.4 million people (nearly a third of the population) unable to get enough food to live active and healthy lives. Eight and a half million people (37 percent) persist on the borderline of food insecurity with an estimated 400,000 people each year affected by natural disasters (droughts, floods, earthquakes or other extreme weather)

As a consequence Afghan people experience significantly lower incomes and related health effects putting them at the risk of food insecure conditions (2008, WFP).

In Afghanistan, both inadequate and inappropriate post-harvest storage contribute significantly to food insecurity (USAID, 2009). The first concern is the absence of an adequate amount of storage structures, both at the household and national levels. This can result in limited access to food and increased price volatility, conditions which drive food insecurity. A critical concern is the persistence of poor storage management's, contribution to sizable post-harvest losses and lower quality food grain. Post-harvest losses and lower quality continue to lower agricultural income and reverse progress toward food security. Thus, while agricultural development and food security programs are focused on improving varieties and seed quality, fertilizer access and use, and general production practices evidence supports an extension of that agenda into the post-harvest program for gains to be fully realized (Hector and Favre, 2003).

2.4. Storage Efficiency

Physical grain storage is the placing of grain in a protective area to minimize its quality deterioration. Grain is a major asset in which the grower has invested preparation, sowing, and harvesting costs. The asset must be protected because while grain is in storage its quality and value can rapidly deteriorate. It is important to understand whether Afghanistan needs new storage technology introduced or some changes to modernize current traditional systems to advance its industry and decrease the post-harvest losses that can be attributed to inadequate storage conditions. Currently, an efficient grain storage and marketing infrastructure is not in place, preventing farmers and small traders from holding their stocks for longer periods and compelling them sell to intermediaries at or shortly after harvest (Hector and Favre, 2003).

Afghanistan faces serious storage problems on a large scale throughout the country attributable to management practices primitive methods of storage. Storage has remained a priority area for agricultural growth and reducing food insecurity in the country. Afghanistan's traditional systems of storage are vulnerable to a number of threats to grain quantity and quality such as sprouting, molding, rotting, as well as zootic pest damage.

In Afghanistan climate conditions may impact storage via rainfall at harvest time, improper ventilation or aeration, inability to control storage space temperature and humidity, and contamination in the storage receptacle or space. Limited technology and capital for investing in storage may lead to unclean reused or out of condition bags, stored seed with high foreign matter containment and improper or absent spray and fumigation control. While grain losses and grain quality deterioration due to the above factors are serious issues, inadequate on-farm or commercial storage is another issue. Grain storage and post harvest handling facilities are sorely underdeveloped or limited.

Post-harvest losses of stored grain by farm households are estimated to be between 15 and 20 percent based on recent research (USAID June 2006; FAO and

Ministry of Agric., Irrigation, and Livestock). A mere three point reduction in this estimated loss represents an increase of 75000-100000 MT of wheat grain available for domestic use (FAO and MAIL, 2008). In table (2-1), the wheat balance sheet (including the post harvest losses) for six provinces is presented. This data in the table indicate that the post-harvest losses are higher in provinces with warmer than average weather (Helmand and Kandahar) and lower where conditions are relatively cooler (Ghazni and Zabul). The increased post-harvest losses in warm-weather provinces is associated with the temperature driven increase in activity and infestation level of molds and other biological pests.

Table 2-1 Wheat Balance Sheet-Total Uses and Losses (thousand metric tons) in Southern Afghanistan in 2005

Province	Total Availability	uses or needs	Seed provision	Post-harvest Losses	Total utilization	Surplus/ deficit
Helmand	213	126	14	32	172	41
Kandahar	98	152	7	15	173	-75
Zabul	30	41	2	5	48	-18
Uruzgan	86	106	6	13	124	-38
Ghazni	147	152	10	22	184	-37
Ghor	78	52	7	12	101	-23
Total south	652	6 95	46	98	802	-150
Afghanistan	4266	3788	295	640	4327	-457

Source: United States International Development Agency (USAID)

The table above reports fairly high post-harvest losses (ranging from highest of 32 thousand metric tons of total regional production in Helmand to lowest of 5 thousand metric tons of total regional production in Zabul) and there are many factors contributing to these losses. Traditional storage facilities like mud bins, small rooms made of brick, straw, or wood do not provide significant protection against insect infestation and cannot be made gas impermeable to facilitate fumigation. The technological standard in the developed world has long been concrete or metal storage silos that can effectively be fumigated and maintained efficiently with minimal wear. As a result, much of the published existing research on post-harvest losses is oriented toward management of silo stored grains with little work having been completed on older and small systems which form the backbone of food grain storage in Afghanistan and the rest of the least developed world.

2.5. Recent Contributions to Grain Storage in Afghanistan

Afghanistan is a chronic food deficit country, and one of the most serious concerns is food insecurity. The United States, the international community, the United Nations, and the Afghan government have committed significant investments to improving agriculture and the food security condition of Afghanistan. In terms of post-harvest management, the support programs range from training Afghan farmers about post-harvest procedures to the rehabilitation of different public storage facilities, as well as the distribution of grain storing equipment to households in the rural areas.

The FAO in conjunction with the Ministry of Agriculture (MAIL) has developed a program to improve adoption of proper storage and post-harvest handling strategies. This partnership has also focused on renovating and revitalizing key storage infrastructures that remain operational in the country. This includes a number of grain silos and flour mills as well as new construction. FAO has distributed 1400 locally produced metallic silos providing grain storage capacity from 120 to 1 800 kg to be used by individual farmers, farmer groups, and cooperatives. The aims are to help reduce post-harvest losses, improve grain quality, increase the income of farmers by facilitating off-season marketing, and enhance household food security (FAO, MAIL 2009). Another entity, USAID has focused effort on rebuilding cold storage warehouses for the government and training Afghan farmers to manage storage and handling problems.

The World Food Program (WFP) has worked in Afghanistan since 1963, and is currently active in all 34 provinces. In recent years, WFP's focus has shifted from emergency assistance to rehabilitation and recovery of public storage facilities. WFP has been working on grain storage and food security, primarily in remote and food-insecure rural areas and has been promoting flour fortification in Afghanistan since 2004.

2.6. Conceptual Framework for Grain Storage Concerning Grain Quality

2.6.1. Stages of Post harvest System and Losses

The post harvest system can be defined as the delivery of crop from the time and place of harvest to time and place of consumption. An efficient storage system will minimize losses in the effective quantity of grain. Generally, the post-harvest system encompasses a sequence of activities and operations that can be divided into two groups. Technical activities include harvesting, field drying, threshing, cleaning, additional drying, storage, and processing. Economic activities consist of transporting, marketing, quality control, nutrition, extension, information and communication, administration and management.

Post-harvest procedures vary depending on the farm size. Moreover, post-harvest systems vary from country to country and region to region. Despite this, we can identify some basic principles post-harvest systems in terms of the management demands imposed by threats and when they occur without regard to many of the specifics of a given system. At its core, the agro-food chain starts from producers and ends with the consumer in all instances. Figure (1) outlines a “complete” or idealized post-harvest dynamic system, which is complex and includes many logically interconnected functions and operations.

(Source: GROLLEAUD, 2002)

(01)	HARVESTING handling
(02)	THRESHING
(03)	DRYING transport and distribution
(04)	STORING
(05)	PROCESSING
(06)	PRIMARY PROCESSING cleaning, classification, dehulling, pounding, grinding, packaging, soaking, winnowing, drying, sieving, whitening, milling
(07)	SECONDARY PROCESSING mixing, cooking, frying molding, cutting, extrusion
(08)	PRODUCT EVALUATION quality control: standard recipes
(09)	PACKAGING weighing, labeling, sealing
(10)	MARKETING publicity, selling, distribution
(11)	USE recipes elaboration: traditional dishes new dishes
(12)	CONSUMER PREFERENCES product evaluation, consumer education

Figure 2-1: Diagram-Stages of a Whole Post-harvest System

As discussed, in the previous diagram a complete post-harvest program includes several complex stages, many of which may not occur on farm. The most common steps followed by a farmer starts at harvest and ends at the end of the storage period, outlined in detail in the following table along with potential damage threats to the stored grain.

Table 2-2:Post-harvest Stages/Operations Occur On-Farm

Stages	potential problems
Harvest and Field drying	Birds, insects, molds, sprouting, fall off, other wild life
Transport	Spoilage, bruising, breakage, leakage
On-farm drying	Moulds, bacteria, sprouting, rancidity, Domestic animals and birds, rodents, other wild life
Cleaning	breaking, cracking, spoilage, chemical contamination
Storage	Insects, rodents, molds, bacteria, sprouting, and rancidity

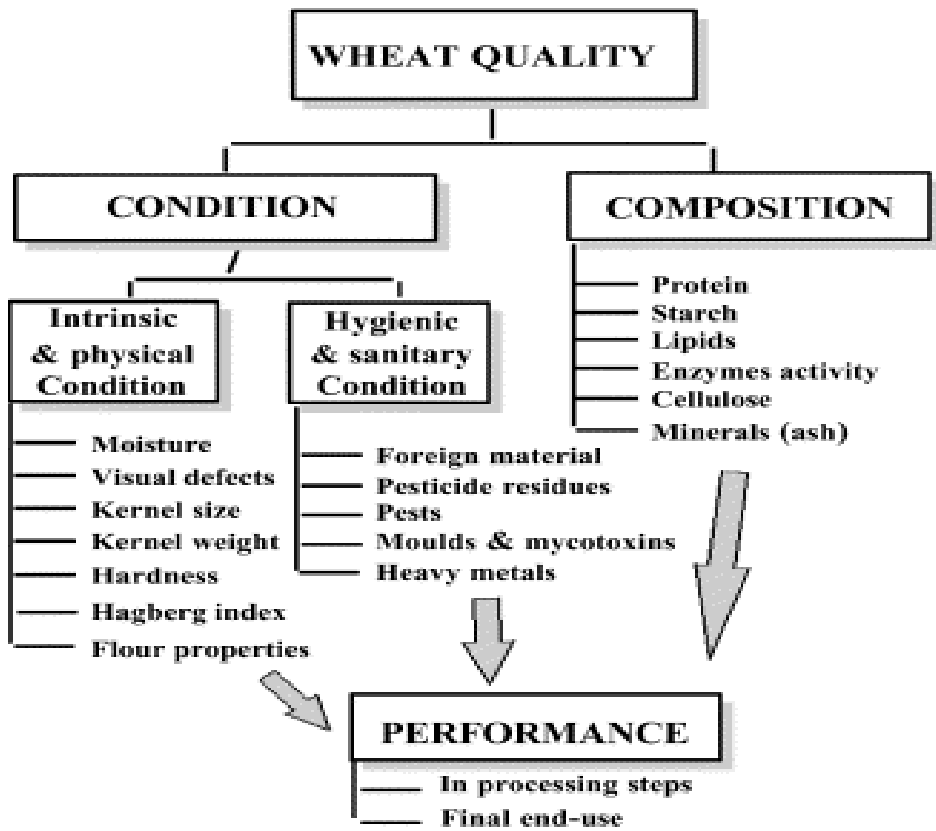
Source: Food and Agriculture Organization of the United Nations, 2002

Food grains are at risk in each stage, which raise the potential for significant losses. Losses refer to total modification or decrease in terms of quantity or quality making the food grains unsuitable for human consumption. Loss should not be confused with damage. Damage is a clear deterioration in the grain such as broken or pitted grain, which affects more its quality than its Both damage and loss should be quantified in terms of weight and cost. Damage restricts the use of grain, whereas loss makes its use impossible.

As argued earlier, post-harvest losses can be in term of quantity and quality, depending on the potential threats after harvest. Any physical loss that reduces the weight and volume is called quantitative loss, which can be easily measured. It is often the result of prolonged infestation and consumption by insects, rodents and birds or poor packaging. Sometimes weight loss does not necessarily mean food loss. Weight loss can occur due to moisture reduction (especially when it results from drying), which is not considered, yet a high moisture content can produce serious damage resulting in qualitative loss. On the other hand, qualitative is particularly concerned with the nutritional and reproductive value of grain and requires a different kind of evaluation done mostly in laboratory**.** The criteria for qualitative losses are evaluated based on external features, shape, size and taste.

2.6.2. Factors Causing Losses and Effect Stored Grain Quality

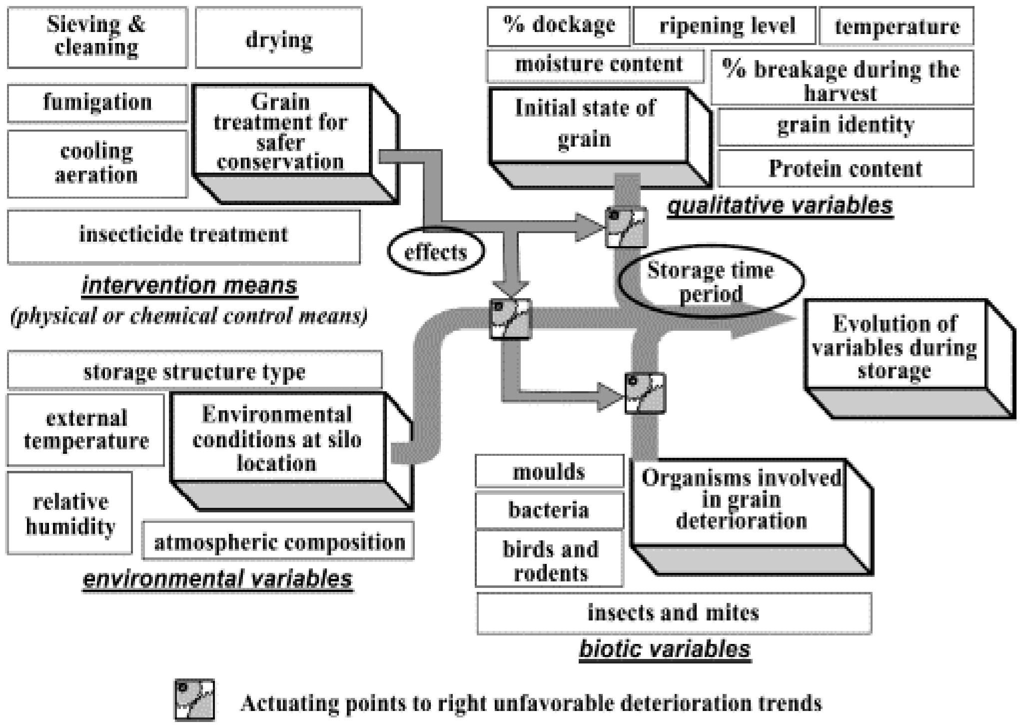
The term quality in grain industry includes a wide range of qualitative characteristics that can be defined in terms of physical, sanitary and intrinsic properties. Physical characteristics are mostly about the moisture content in grain, weight, grain size, total damaged grains, heat damage, broken grains, stress cracking, breakage susceptibility, etc. Sanitary properties of grain is determined by fungi and mycotoxin count, level of infestation, rodent excrements, foreign material, toxic seeds, pesticide residue, odor, and dust. Intrinsic quality is related to grain constituents such as protein content, hardness, density, starch content, viability, and storability. Although intrinsic quality is mostly determined genetically, environmental factors can greatly affect grain physical and sanitary qualitative properties. The following diagram shows the complex component of wheat grain quality and market value.



Source: (Fleurat-Lessard, 2001)

Figure 2-2: The Component of Wheat Quality Influencing Market Value of Wheat

The quality properties of a grain are affected by its genetic traits, the growing period, timing of harvest, grain harvesting and handling equipment, drying system, storage management practices, and transportation procedures. All the major components of quality will change overtime under the influence of storage environmental conditions (e.g. temperature decreases after harvest, relative humidity changes and the presence of foreign materials or pests), living insects, molds and associated mycotoxin, foreign seed species, heavy metals, and pesticide residues, which are the major sanitary and safety components of quality, are under the influence of storage conditions as well. Thus, managers of grain stores must comprehend the ecological, economic and technical consequences of their actions. Quality and nutritional changes that occur during storage of cereal grain are the net result of interactions within a complex ecological system. The factors shown in the following diagram affecting the quality and describe their interaction with each other in stored grain environment.



Source: (Fleurat-Lessard, 2001)

Figure 2-3 Functional Diagram of Complete Relationships Existing in the Stored Grain

The main interacting factors in the diagram are environmental factors, storage operation, deteriorative causes and the initial condition of grain. Because each component influences the quality and can cause qualitative and quantitative losses, the grain holder's knowledge about all the components is crucial for quality retention during long-term storage.

2.6.3. Managing Stored Grain Quality and Application of S.L.A.M Management Strategy

It is critical to carefully manage stored grain to prevent grain deterioration and possible serious economic loss. Part of this management should include a well designed and properly operated storage system. Grain quality will not improve during storage. At best, initial quality can only be maintained. Once grain is stored, the quality depends on the control and management of the storage system (Buschermohle, Pordesimo and Wilhelm, 2008).

Grain spoilage is ideally prevented by adopting an integrated multidisciplinary approach to find the most economic way to maintain grain quality by protecting it from pests and other deteriorations (Fleurat-Lessard, 2002). For pest problems, accurate and timely diagnosis of the pest issue to begin the correct remedy is incumbent on the manager. All ecosystem factors mentioned previously must be taken into account as part of the remedy. The main objective of management of the stored grain ecosystem is to ensure minimal deterioration in any variable associated with quality so that the grain lot remains suitable for the end-user.

One approach to maintaining grain quality is to follow a Sanitation, Loading, Aeration and Monitoring S.L.A.M post-harvest integrated pest management (IPM) strategy. The idea of the S.L.A.M is to maintain high post-harvest quality of stored grains against pests, molds, rodents and self-heating. Though the S.L.A.M. guidelines are described for rather industrialized agriculture in the literature, the principles for management persist across all environments. S.L.A.M is almost exclusively focused on preventing grain from potential losses as opposed to more common approaches that employ treatments or other actions once the damage process has begun. Each of the proactive S.L.A.M steps is applicable in grain storage management in any storage system, needing only to be modified to consider working conditions of the particular farm storage case (Mason and Woloshuk, 2010).

In developing countries most farmers have limited access to chemicals for treatment and may have difficulty in properly employing them, thus applying S.L.A.M principles represents an ideal starting place for developing an impactful storage loss program in Afghanistan.

According to S.L.A.M strategy, the management has to take place from the time of harvest. Proper actions are required as grain is harvested and transferred to on-farm storage. This minimizes the chance of problems necessitating expensive reactions later in the storage period. In addition to the condition inside storage facility, storage life of grain and grain losses are affected by a number of pre-storage factors at different stages starting from harvest. These include harvest time (maturity) and method and management practices such as threshing, cleaning and drying which together determine the initial condition of the grain. Initial condition of grain is defined by seed maturity, moisture content; harvest/thresh damage rate, and cleanliness (i.e. foreign material in gain). As initial conditions of the stored grain improve so too will its storage life leading to a reduction in quantity and quality losses (Mason and Woloshuk, 2010)

Grain lost at harvest is a direct loss of income as well as affecting the initial condition of grain loss at harvest results from shattering or mechanical damage when threshing the crop. Harvest time is important as well since harvesting too late will increase grain's field exposure to birds, rodents, and insects. Harvesting grain before complete maturity however threatens high moisture content in seed and an increased risk of breakage during threshing.

In Afghanistan, wheat is commonly harvested with hand sickles. Mechanical damage to seeds may be high depending on equipment condition and skill of the harvester. Moreover, sickle harvest slows down the process increasing the length of harvest period. , In Afghanistan, wheat harvest usually starts in May, June or July depending on the area. Harvest time is not fixed and is traditionally determined by farmers' observations from the field. Understanding that harvest methods in the country are very primitive and most of the farmers lack understanding the proper time of harvest, reducing grain losses at this stage offers promise with education and investment aimed at farm owners and workers.

In Afghanistan, threshing is usually done by oxen and threshing machines. High rates of mechanical damage to the seed may occur during threshing, leading to direct losses of grain and introducing pests. Damaged grain during threshing is more susceptible to the attack of molds and insects in storage and has a shorter storage life.

Storing unclean grain which contains a significant amount of foreign materials will lead to losses due to the molds and insects present in the material. Cleaning is usually done by hand using screens. Using better threshing methods and technology leads to cleaner grain for storage reducing effort required to clean. In the current system of threshing and cleaning in Afghanistan, there is high possibility of placing unclean grain in the storage facility increasing later damage during storage.

Drying is another pre-storage operation that determines the initial condition of grain. Storing grain with high moisture content provides opportunity for mold growth and infestation during the storage period, which contributes to losses. In Afghanistan, grain is usually dried in the sun, which might not decrease the moisture to an optimal level. This “extra” moisture is transferred to the storage facility and affects the storage life of grain while increasing the chance of infestation and molding.

Although grain losses and storage life are highly dependent on the initial grain condition, after the grain is stored in a storage place, the losses and storage life of grain depends on the storage facility or method itself, as well as all the management practices done in order for to control the storage environment. During this period losses and quality deterioration are caused by molds, improper control of temperature and moisture in the storage place, as well as infestation. These depend on the storage facilities, storage system and management practices (Mason and Woloshuk, 2010).

CHAPTER 3. THEORY, DATA, AND MODEL

The previous two chapters discussed the broad wheat harvest and storage loss problem in Afghanistan. In this chapter we narrow the focus on the problem to a representative household's management and consumption choices so that we may better understand the mechanisms that lead to losses at the household level. Limited data exists for examining post-harvest grain management at an aggregate level, so we focus squarely on the individual case considering a household that is assumed self-sufficient in wheat production for all of its members and can sustain this harvest by producing enough seed for the next year.

Reducing losses in farm household stored grain quantity and quality requires careful planning to ensure that facilities and management practices are consistent with an objective of maintaining the grain crop in its best use condition. In this study a conceptual model is developed to investigate farm household storage management in Afghanistan. The representative household approach makes explicit assumptions about family needs for food security in the current and future periods by considering monthly food consumption as well as reserve holding for seed in the next season's crop. With limited farm level data we make a number of assumptions about status quo storage practice in the representative household, identifying the potential gains in food security that can be made with marginal management interventions.

The household storage model is linked to a simple biological model of insect infestation, allowing monthly climate data to determine insect population growth and by extension grain damage. Thus, the infestation model and household storage model provide a context for considering specific interventions such as triple bag storage or S.L.A.M management in a general form by changing an appropriate exogenous variable of the system. Economic impacts in the model are inferred in terms of the representative household's food security status.

The model is primarily conceptual portraying the scope of the current grain storage system and management practices to reveal connections between storage practices and household requirements, and providing guidance on research data needs for specifically addressing problems related to the Afghan household storage. The linkage to an infestation model underscores the timing elements of storage management practices and how they fit into the biological population cycle of pest insect. Assumed values for damage from insect population damage are included to make explicit the quantitative loss during the storage period using available data on the most common insects impacting stored grain in Afghanistan, the biologically similar granary and rice weevils.

S.L.A.M storage management strategy and triple bag storage system as storage interventions are introduced into the model in a generic fashion, by assuming a change in one of these leads to a change in an assumed exogenous model variable (e.g. surviving insects per generation). The model can be used to predict expected reduction in loss associated with storage improvements. Although the interest of this study is to specially deal with wheat storage, the principles may apply to most cereal and feed storage as well.

The framework model is benchmarked to the amount of grain a representative farmer needs to place in storage at harvest to meet grain requirements over the course of the following year. This includes the household's pattern of consumption, reserve holding for seed and expected (quantity and quality) losses that deplete the effective quantity stored over a year. Understanding the general storage needs will allow us to focus on the pattern of losses that occur in the stored grain.

The primary query in general storage requirement framework to deal with is the initial amount of the quantity that a representative farmer must store over a year. This requires an understanding of the attributes of the representative farm. A reliable estimate for the initial quantity that should be stored over a year directly depends on the amount of grain that a representative farm household consumes, the amount of grain stored for seed, the buffer stock that the farmer would like to hold and the proportion of losses that a famer expect over a year in the stored grain. The discussion of these elements in setting that benchmark case for the model is provided in the next section.

3.1. Assumptions and Attributes of a Representative Farm

For this study, it is assumed that a typical farmer in Afghanistan stores grain for a year starting at the harvest time till next harvest. This harvest occurs in the month of May. The model assumes an idealized path of consumption over the period of a year and a planned 20% loss (on the initial stored amount) during the annual period. Moreover, the model consists of an assumption that a representative farmer must hold a particular amount of grain for seed for the course of seven months (i.e. at the start of the next planting season a sufficient amount of grain will be removed from the storage to replace the previous harvest). Households in rural areas in Afghanistan often consist of an extended family where several generations share the same houses and live on the farm. The household size is consequently rather large relative to the size of the farm. As shown in the table (1), the national mean per household is 11.4 persons.

Table 3-1:Farm Household and Population by Household Size: Agriculture and Food Production in Post-War Afghanistan, FAO 2003

	Households	% households	Population	% population
Total	1,065,523	100	12,103,964	100
Household size (persons)				
2-5	59,017	5.5	258,086	2.1
6-9	424,333	39.8	3,300,295	27.3
10-14	369,362	34.7	4,172,089	34.5
15-19	117,773	11.1	1,901,258	15.7
20-29	70,470	6.6	1,555,428	12.9
30+	24,569	2.3	916,807	7.6

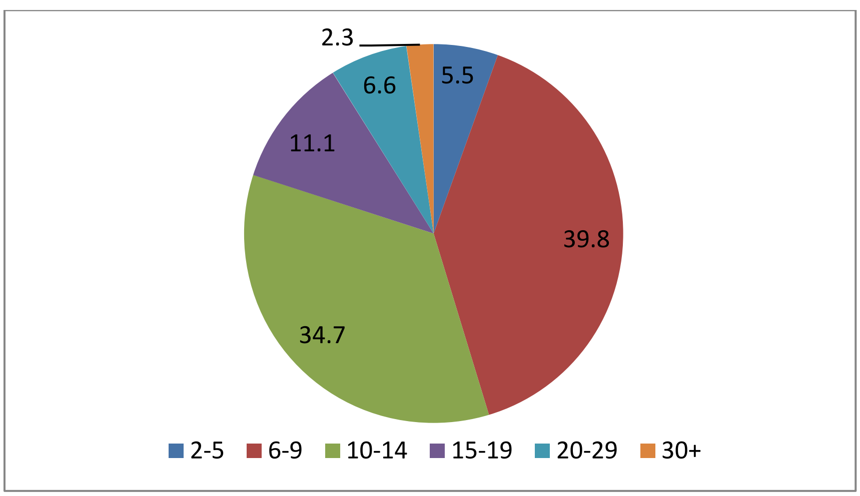


Figure 3-1: Household Size-Percentage of Households

From the figure above, nearly seventy-five percent of households correspond to a household size of betwen10-20 persons; while quarter of the households correspond to a household size of more than 20 persons.

The data on farm size show that most of the farms in Afghanistan are very small. As shown in the table (3-2), few farms operate an area larger than 10 hectares. Farmers with irrigated land manage an average of 3.24 Ha, while farmers with rain-fed land control operate 7.36 Ha of rain-fed land. However, a majority of farms have on average less than 5 hectares of arable land with about two-thirds of that being irrigated.

Table 3-2: Farms with Irrigated and Rain-fed Land by Farm Size: Percentage of Farms and Percent of Area
Data Source: Agriculture and Food Production in Post-War Afghanistan, FAO 2003

	Total Farms		Farms with irrigated land		Farms with rain-fed land	
	Farms	arable land (Ha)	Farms	Irrigated land (Ha)	Farms	Rain-fed land (Ha)
Total	100.00	100.00	100.00	100.00	100.00	100.00
Below 0.50 Ha	13.43	0.80	14.25	1.60	3.21	0.11
0.50-0.99 Ha	11.52	1.29	12.08	2.38	5.66	0.34
1.00-1.99 Ha	17.66	3.90	18.62	6.79	12.38	1.37
2.00-4.99 Ha	26.10	13.47	25.82	19.29	28.64	8.38
5.00-9.99 Ha	14.93	16.64	13.81	18.16	21.85	15.31
10.00-19.99 Ha	9.29	19.75	8.67	18.36	15.61	20.96
20.00-49.99 Ha	5.53	25.93	5.35	18.83	10.04	32.14
50+ Ha	1.54	18.21	1.38	14.59	2.62	21.38

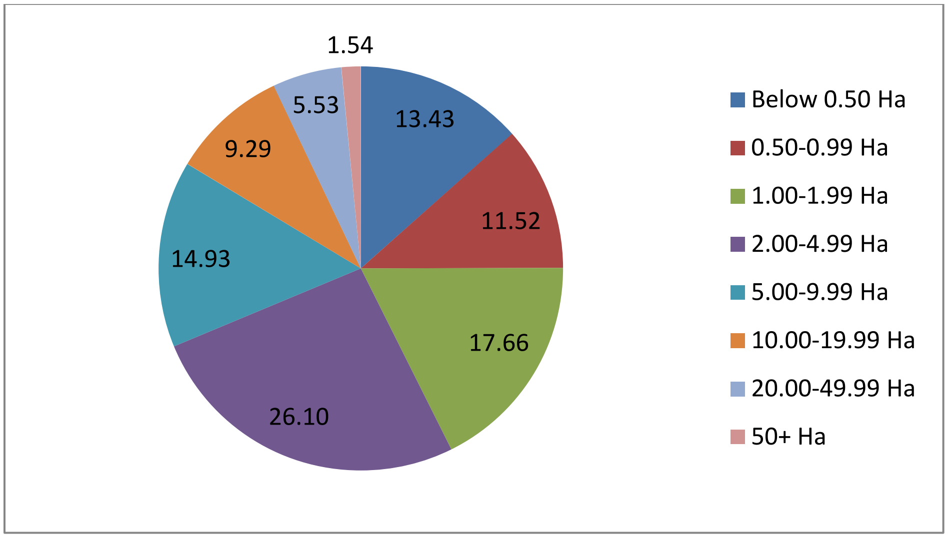


Figure 3-2: Number of Farms by Farm Size in Hectares of Arable Land

In the figure above, about 16% of the farms have an area of 10 or above 10 hectares; about 14 percent of the farms have an area between 5 and 10 hectares, whereas almost 70% of the farms have area below 5 hectares.

Using the data above on farm household size and farm sizes, we assume the representative farm to be 2.5 Ha of arable land with a household size of 12 people who operate and live on the farm. About 60% of the caloric intake of rural Afghan population comes from the wheat crop, leading to the assumption that 70% of the total area is cultivated dedicated to wheat cultivation. This fact is also illustrated in the following figure.

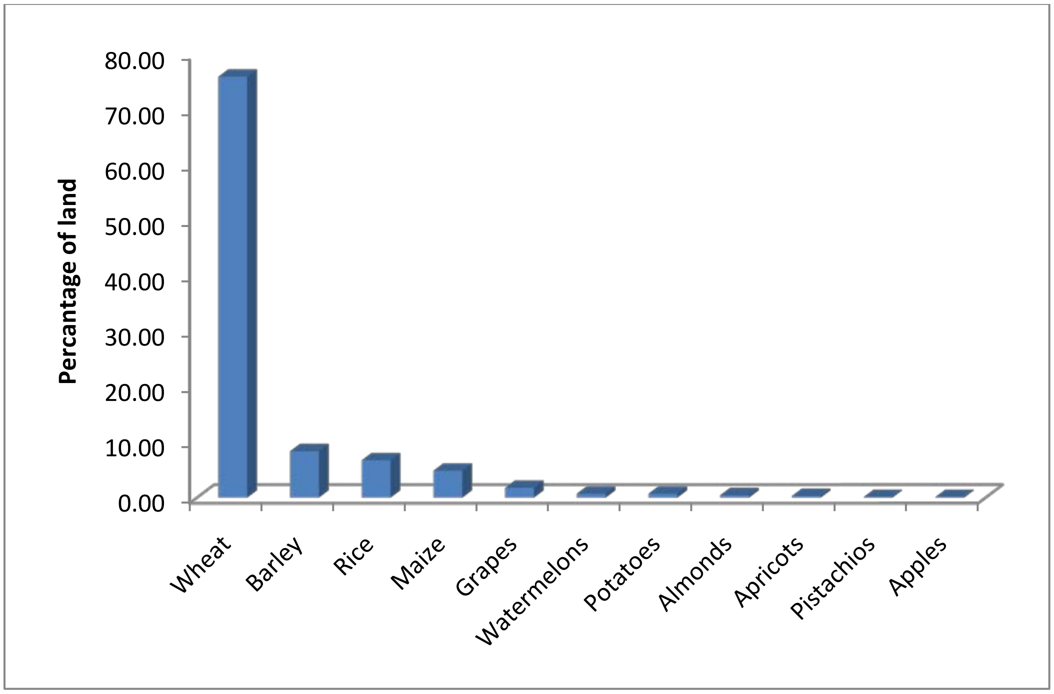


Figure 3-3: Cultivation by Crop-Percentage of Land

The wheat requirement per capita in Afghanistan is estimated to be189 kg over the period of a year (Paul A doorsh). Table (3) summarizes the critical attributes of the assumed representative in Afghan household used this study.

Table 3-3: Summery Characteristics of a Representative Farm Household in Afghanistan

Farm size (Ha)	2.5
area under wheat cultivation(% of total land)	70%
Proportion of area under wheat cultivation (Ha)	1.75
Farm household size	12
Annual Per capita consumption (Kg)	162.6
Total storage period assumed (months)	12
Total quantity consumed by household in each month (Kg)	162.6
Total consumption (kg) over 12 months	951
seed stored for sowing (kg) based on 150kg/Ha of application rate	62.5
Buffer stock assumed (% of total consumption)	5%
Buffer stock (5% fraction of the total consumption)	98
Total loss (20% fraction of the total grain goes to storage)	20%
Post harvest losses (% of the total grain goes to storage)	462
Total quantity "should be" stored for 12 months (kg)	2774

Using the information above in the table, the total quantity stored over a year by a representative farmer is estimated to be 3135 kg of grain. The total quantity is mainly split into four parts, which are quantity stored for seed, consumption, the buffer stock and the fraction of expected losses.

Such large households and small farm size imply that a livelihood based on agriculture as the main source of food or income should be endowed with a sufficient area of cropland to produce the food needed. Having estimated that per capita consumption of wheat is 189kg annually, about 2.5 metric tons of wheat is required for a representative household to place into storage annually. However, consumption and reserve for seed holdings must not be the only considerations of a farmer to feed his family over a year. He or she must plan for the 20% post harvest losses during the storage period. This requires about three metric tons for a representative farmer to be self-sufficient, while accounting for losses, seed reserve, consumption, animal food or any other non-food uses.

Figure 3-3 shows total grain storage needs for a representative farmer over a year. Beginning with the harvest period in May, the total quantity that must be held for a year is a combination of stored seed for the next season sowing (stored for 7 months), constant monthly consumption, and 20% loss over time due to a combination of different factors.

Total Quantity stored= seed reserve +Consumption+ 5% buffer+ 20% loss

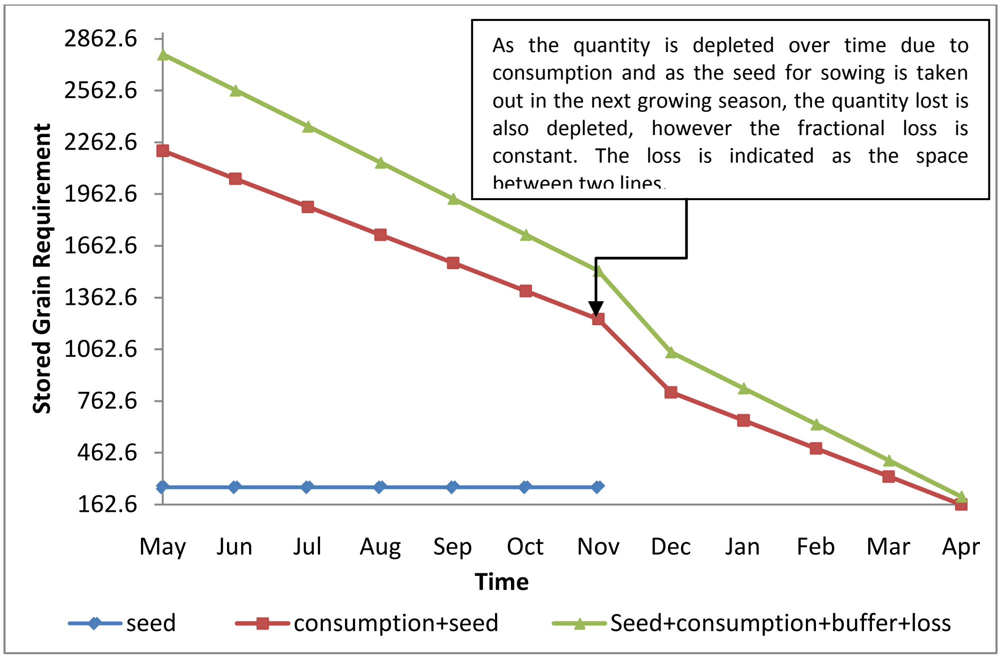


Figure 3-4: Household Storage Requirement for the Course of a Year

The core element to notice from the storage requirement framework is the pattern of storage loss over time, which is the main focus of this study. The assumed 20% loss is shown in the graph as a constant difference based off of the average value; however, the actual loss will vary over time and, in particular, the fraction of loss caused by insects will be non-linear due to exponential population growth of the insects in the storage place.

Although the quantity stored is depleting over time, the fraction of remaining grain lost may be increasing depending on the insect multiplication and growth rate. To investigate this pattern of losses with respect to time and potential management interventions for reducing losses requires analysis of insect growth. Insect growth and the multiplication rate are assumed to depend singularly on the climatic conditions (proxied temperature) in the place where grain and insects are stored. We now turn to the insect growth and development model which underpins the grain damage and loss that we explicitly model for the household.

3.2. Insect Growth and Development

The growth rate of many insects is controlled primarily by temperature. Due to the fact that insects are cold-blooded, their body temperature varies as the temperature of their surrounding environment varies. They require a certain amount of heat to develop from egg to adult and complete their life cycle. Insect growth only occurs within a certain range of temperatures, the upper and lower developmental thresholds which are different for different species of insects. Growth increases as the temperature above the minimum threshold level increases till the upper threshold is surpassed. The minimum threshold for granary and rice weevils is 16 C (60.8F) and RH of 30%, the optimum temperature is 30 C (85F) and RH of 75%, and the maximum temperature is 36 C (96F) (Mason, 2010).

Determining when an insect pest will appear is often a difficult task. Depending on the variation in weather patterns, insect development may vary by a couple of weeks each year. This makes it difficult to predict insect growth stages using a calendar. Determining when an insect will appear should be based on some kind of temperature-based function, such as a phenology. A phenology model helps predict the timing of events in an organism's development using a constructed value of temperature over time, timed degree-days.

The temperature or heat that an insect requires to complete its life cycle is known as the physiological time and is measured by the heat units called Growing Degree Days (GDD’s). Degree-days measure insect growth and development in response to daily temperatures. Degree-days are the accumulation of heat units above some temperature (the lower threshold) for a 24-hour time period. One degree day results when the average temperature for a day is one degree over the minimum threshold. Accumulated degree days are graphically represented by the area under the curve within the upper and lower thresholds in Figure (3).

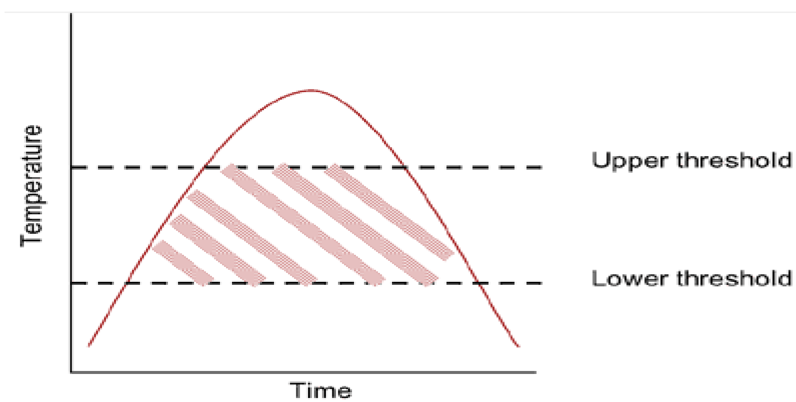


Figure 3-5: Minimum Threshold, Maximum Threshold, and Accumulated Degree Days

Degree-days can be calculated by several methods. The simplest method and general equation used to calculate degree days is as following:

Equation 1: Simple Method of Degree-Days Calculation

$$\left(\frac{\text{Maximum + Minimum temperature}}{2}\right) - \text{Minimum threshold}$$

* If minimum temperature < minimum threshold,
set minimum temperature = minimum threshold.

* If maximum temperature > maximum threshold,
set maximum temperature = maximum threshold.

Due to the lack of systematic data on temperature in Afghanistan and as the daily temperature is not available, GDD's are calculated using mean monthly high and low temperatures. The data is an ambient temperature collected outside in the field but for this study we are interested in the temperature where the insects are located (inside storage place). Since grain is usually stored inside a room, the temperature inside the room is likely to be slightly warmer because some heat from adjacent heated rooms will move into the unheated room, the room itself holds some heat, and the grain and insect respiration will produce some heat that may raise the temperature a little in the container in which the grain is stored. Accounting for this fact, we added a constant number to the outside temperature to approximate the inside temperature. So, for each month, we use the mean high and low monthly temperature plus a constant equal to 10 degrees Fahrenheit to get the number of heat units for each particular month and day. Figure 3-5 graphically shows the temperature and relative humidity starting at the time of harvest.

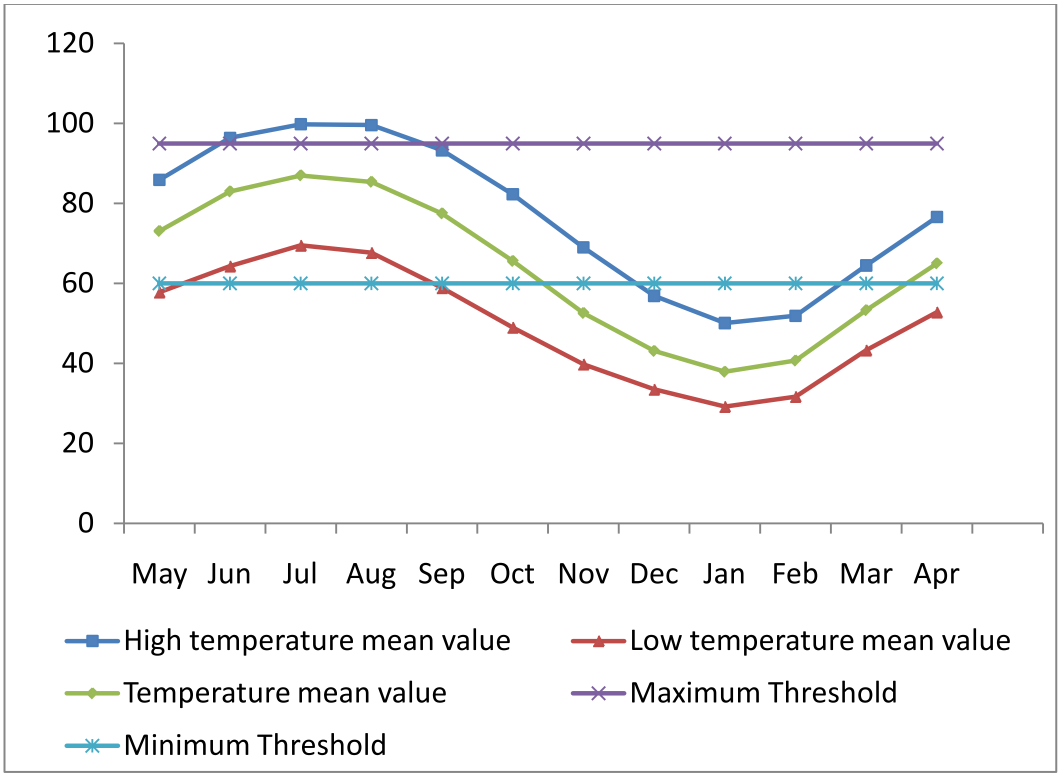


Figure 3-6: Temperature and Relative Humidity inside the Storage Place in Kabul Afghanistan

The graph above shows the maximum and minimum monthly temperature inside the storage place. Also, it shows the minimum and maximum temperature thresholds for rice/granary weevil. As we will discuss in the following sections, we assume the insect doesn't reproduce or it hibernates as the temperature goes above the maximum threshold or falls below the threshold level.

Table 3-4: Temperature and GDD Calculated

Statistic	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
High temperature mean value (F)	86	96	96	96	[illegible]3	82	69	69	57	50	65	77
Temperature mean value (F)	73	83	87	85	78	66	53	43	38	41	53	65
Low temperature mean value (F)	60	64.3	69.5	68	60	60	60	34	29	32	60	60
Relative humidity (%)	48	36	37	38	39	42	52	63	68	70	65	61
GDD (heat units) daily	13	20.15	22.8	22	17	11	4.5	0	0	0	2.3	8.3
Degree days in each month	389	604.5	683	656	500	335	135	0	0	0	68	249
GDD cumulative	389	978	1645	2286	2785	3120	3255	3255	3255	3255	3322	3571

Having the temperature data of the storage place and using growing degree day's equation in equation 1, the degree days have been calculated as shown in the table (4). Because there is no data on daily temperatures, the best can be done is to use the average monthly temperatures to calculate degree days in each month. Therefore, in May it is estimate that 12.95 growing degree days will be accumulated each day. The estimated degree days for each month are then multiplied by 30 to estimate total degree days or heat units in each month. Figure 3-6 shows degree days in each month and cumulative degree days over the storage life.

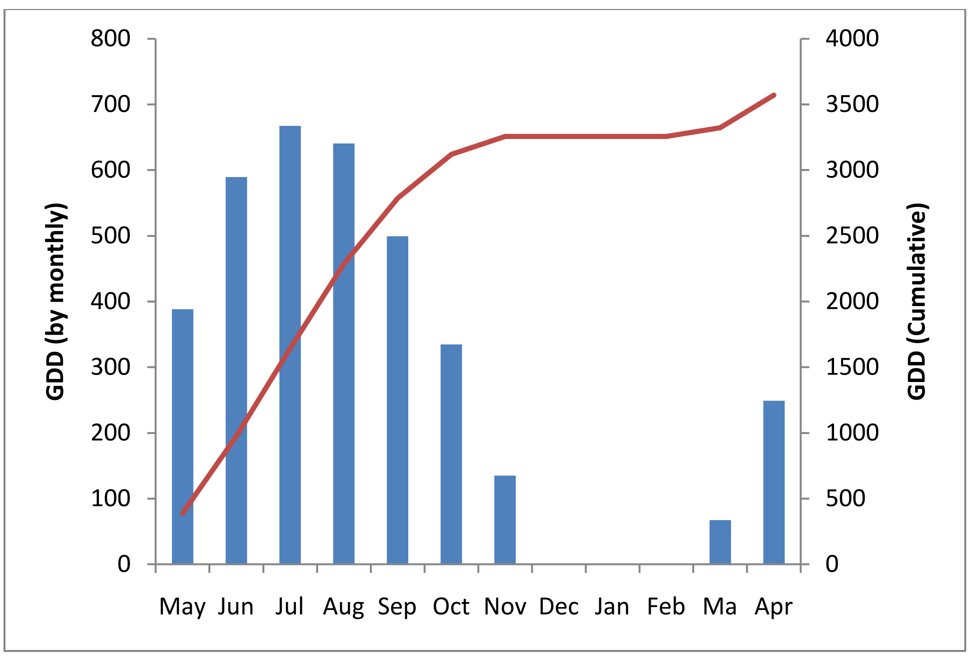


Figure 3-7: GDD Monthly and Cumulative

The accumulation of degree-days is added over a period of time and used to estimate growth and predict insect development. The accumulation of degree-days for this study begins in May as it is the time of harvest and when the grain is placed in the storage place.

In order to estimate the number of generations and number of insects over the storage period, it is necessary to understand the multiplicative characteristics of the particular insects considered in the model. As shown in table (5), the average number of eggs one female lays are 150, and the mortality rate assumed to be 85%, therefore the number of adults produce in one generation are 22.5. Since males have a short period of cycle usually 7 days and do not lay eggs for the next generation, the number of adults in each generation should be divided by two to estimate the number of females that are produced in each generation. Therefore, the insect multiplication rate shows that eleven female are produced in each generation.

Table 3-5: : Assumed Reproduction Characteristics for Rice Weevil/Granary Weevil

Number of eggs one female lays	140
Mortality Rate	85%
Number of adults F1	21
number of females in F1	10.5
GDD to complete one life cycle	1000

The number of generations depends on the accumulated degree days over the storage period. It is estimated that it takes 1000 degree days for rice weevil/granary weevil to complete a generation, based on daily highs of 85, a developmental threshold of 60 and an average of 40 days to complete the life cycle. Therefore after accumulating each 1000 degree days will determine the length of generations until the end of the storage season. Based on the degree days calculated and the insect multiplicative characteristics as mentioned above, the insect completes a total of 3 generation over the annual period of storage. After completing 3 generations, the insect is either not able to reproduce or is hibernated.

Starting at May 1st, by June 1st 401.45 degree days will be accumulated; by July 1st a total of 1006 degree days will be accumulated. Therefore, one complete life cycle will be completed by July 1st. By August 1st, another 705 degree day will be accumulated and the insects complete the second generation by August 14. After august 14th, till the end of November the third and last generation will be completed and then the insect is assumed not to reproduce since enough GDD will not accumulate to replicate the current generation before next harvest.

Table 3-6 : GDDs and Insect Reproduction in Each Generation

Period	GDD (t)	GDD cumulative	F1	F2	F3	Total Insects
May	388.50	388.50	0.00	0.00	0.00	1.00
Jun	589.50	978.00	4.08	0.00	0.00	5.08
Jul	667.50	1645.50	10.27	0.00	0.00	11.27
Aug	640.50	2286.00	10.50	71.17	0.00	82.67
Sep	499.50	2785.50	10.50	110.25	331.08	452.83
Oct	334.50	3120.00	10.50	110.25	909.31	1031.06
Nov	135.00	3255.00	10.50	110.25	1157.63	1279.38
Dec	0.00	3255.00	10.50	110.25	1157.63	1279.38
Jan	0.00	3255.00	10.50	110.25	1157.63	1278.38
Feb	0.00	3255.00	10.50	110.25	1157.63	1267.88
Mar	67.50	3322.50	10.50	110.25	1157.63	1267.88
Apr	249.00	3571.50	10.50	110.25	1157.63	1157.63

In table 3-6, we see the calculations used to determine insect growth. We allow for partial generations to be completed, since we are using average monthly data and to smooth out insect population growth over time. As can be seen in the first two months (rows) of the table, 388.50 GDD are accumulated in May, meaning nearly 40 percent of the F1 generation requirement is met. Thus, when June begins, we assume that nearly 40 percent of that generation is active as adults, leading to the value in the F1 column of 4.08. Not until the full 1000 GDD are accumulated (into July) will all of the F1 generation become active and begin reproducing the F2 generation.

As the grain is consumed each month by the household, the amount of grain stored is depleted each month and so the insect population (i.e. as part of grain is consumed the insects are also taken out of the storage so the population is decreasing). We account for the reduction in the total population as grain is taken out each month as shown in the table 3-7.

Table 3-7: Estimated Insect Population After Accounting for Reduction in Grain due to Consumption in Each Period cConsumption

Period	GDD (t)	GDD cumulative	F1	F2	F3	Total Population
May	388.50	388.50	0.00	0.00	0.00	1.00
Jun	589.50	978.00	4.08	0.00	0.00	4.64
Jul	667.50	1645.50	10.27	0.00	0.00	10.20
Aug	640.50	2286.00	10.50	71.17	0.00	73.94
Sep	499.50	2785.50	10.50	110.25	331.08	399.06
Oct	334.50	3120.00	10.50	110.25	909.31	891.13
Nov	135.00	3255.00	10.50	110.25	1157.63	1076.81
Dec	0.00	3255.00	10.50	110.25	1157.63	1036.29
Jan	0.00	3255.00	10.50	110.25	1157.63	974.76
Feb	0.00	3255.00	10.50	110.25	1157.63	866.38
Mar	67.50	3322.50	10.50	110.25	1157.63	665.63
Apr	249.00	3571.50	10.50	110.25	1157.63	57.88

Each generation (F1, F2, and F3) yields 10.5 females per adult, leading to exponential population growth. For the time period considered, the time and temperature pattern allows a total of three generations, such that one initial insect infesting a quantity grain will lead to a total of 1157.6 insects over the annual period of storage (we assume that a female adult has a lifespan of eight months after which she drops out of the population leaving only descendants). Accumulating Growing Degree Days (GDDs) over the storage life of the grain, we identified an exponential growth rate (early in the summer the GDDs accumulate faster, but as the average daily temperature decreases in the winter, the GDD will accumulate more slowly) during the first seven months after harvest for the granary/rice weevils shown in Figure 3-7.

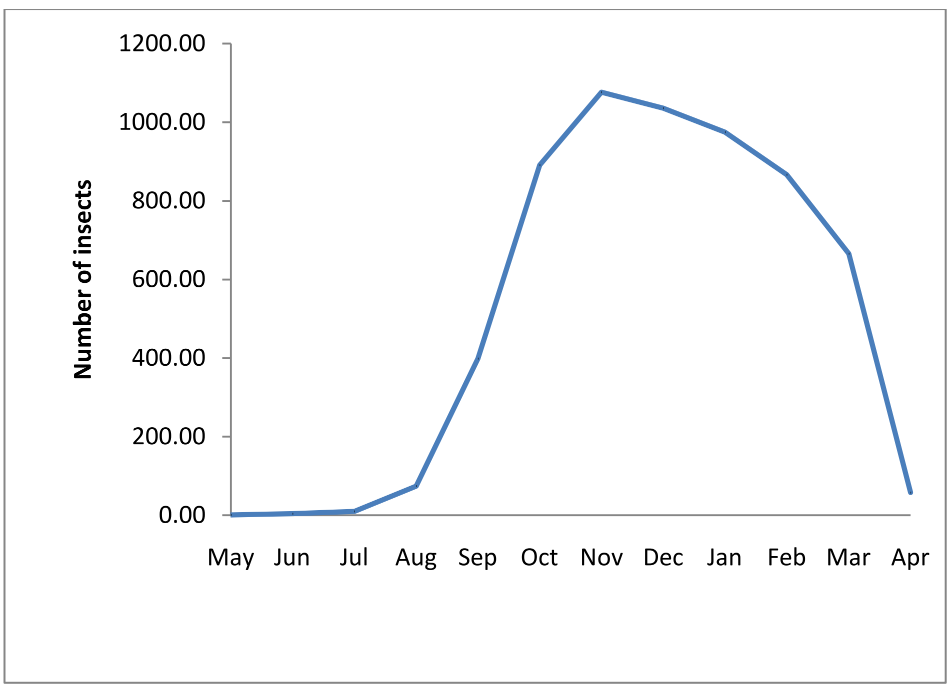


Figure 3-8: Estimated Insect Growth

It is worth mentioning that the insect growth is not necessarily as shown in the figure above. The growth as well as the productivity/mortality and multiplication rate of each insect is subject to environmental conditions which vary from year to year, and even season to season and our use of average values for a month greatly simplifies the actual process and leads to kinked curvature of the above graph.

3.3. The Model

Given the critical attributes of a representative farm defined in the first part of this chapter and the phenology model determining the insect growth over the storage life, in this part the insect growth model is connected to the household storage model aiming to explore and derive the annual consumption path alongside insect driven losses. The losses will be analyzed in terms of the household consumption deficit (i.e. the annual shortfall in consumption that occurs relative to a constant quantity consumed each month). Moreover, given the damages due to the existing insect population, the model will look at the risk facing the household due to shortages as the insect population grows, resulting in increased loss.

Additionally, the model will connect the yield or the amount each household harvest to the amount required to be stored over the course of a year and explore its implication on food security. Given that yield and post harvest losses change from year to year depending on various environmental factors, the food insecure condition may arise even for this representative household that is benchmarked to be self-sufficient in wheat. Therefore, the model accounts for these variations and their implications on total quantity of grain required over the course of a year, thus food security. This will be discussed in detail in chapter 4.

The baseline analysis begins with several assumptions. The first assumption made is about the infestation level. It is important for this analysis to start at some infestation level, which will allow us determine the total losses given a per insect loss and number of insects produced over a year. Per insect loss is not constant and varies as the infestation level (in other words the population density) varies in a particular amount of grain. The baseline assumption on the initial infestation level made and used in the model is 300 females of rice/granary weevils in the total quantity stored. A per female insect loss of 0.00016 kg was found from a published experiment and used in the model. The experiment was conducted showing that 5 couples of rice weevil (*Sitophilus granarius* L) were placed in 1000 grains of wheat of different varieties weighing 40 grams on average, and the average loss was calculated to be 2% per five females (Mabarkia, Rhabe and Guechi, 2010).

Each egg is not able to produce an adult insect. Depending on the environmental conditions, especially temperature and the humidity ratio, the development rate of eggs to the adult stage varies. The survival rate at ambient temperature (field condition) is usually 10%; however, as grain is stored inside the storage places or rooms, the inside temperature is slightly higher, and so the survival rate is higher compared to the field condition. The baseline assumption on the survival rate used in the model is 15% (mortality rate of 85%).

Given that G_0 is the amount of grain placed in the storage place at the time of harvest, which is subject to losses due to insects, the household realizes that such losses may cause shortages during the year, and that they may possibly run out of the grain at some point during the year. For this reason, the model attempts to include a buffer as a forward-looking household's risk factor to account for potential shortages as it tries to smooth out the consumption over the year. The baseline model uses a 5% of the total amount stored as the inter-periodic buffer factor. The risk factor acts as a buffer determining household consumption behavior and its response to losses which may vary depending on the behavior of each individual household.

G_0 is the initial amount of grain at the beginning of first period which is defined by the storage requirement model in the first part of this chapter, and it is thus the total amount of grain available at time t=1.

$$G_1 = G_0$$

However, over time the initial quantity in the storage place is diminished due to consumption and losses. The quantity in storage place in each period is defined as:

$$G_t = G_{t-1} - C_{t-1} - D_{t-1} \quad t \in [2, T$$

Where, t is time period (month), t-1 refers to the previous period, G is grain available, C is consumption, and D is grain lost due to insect damage. In order to explicitly define G_t as it depends on the consumption and damages, the household consumption behavior and the damage by the insect population must be defined mathematically.

$$C_t = (1-\phi)G_t[T-t+1]^{-1} \geq 0$$

Where, C_t is consumption at time period t, ϕ is risk coefficient or consumption smoothing coefficient (set to 0.05), G_t is grain available at period t, T= total number of periods, t= current period.

Household consumption behavior is directly affected by the inter periodical buffer or the risk factor as well as the amount of damages as it is correlated with the quantity grain available at the beginning of each period. As damages increase due to increasing insect population over time, less grain is available for household consumption in the next period (s). However, this still depends on how each individual household responds to expected losses. This will be discussed in chapter 4 in full detail.

Having the damage coefficient for each adult, the initial infestation rate, and population growth found in each period, the amount damaged by insects in each period was calculated as following:

$$D_t = \begin{Bmatrix} if\ \alpha I_t > \sum Gt - Ct & then & G_t - C_t \\ else & & \alpha I_t \end{Bmatrix}$$

Where,

D_t is grain lost due to insect damage at time period t, G_t is grain available at period t, C_t is consumption, I_t is insect population at time period t and α is damage coefficient. The calculated damage over the period of storage is distributed as in the figure 3-7 which is exponential during the insect growth periods and declining as the grain is being removed for consumption.

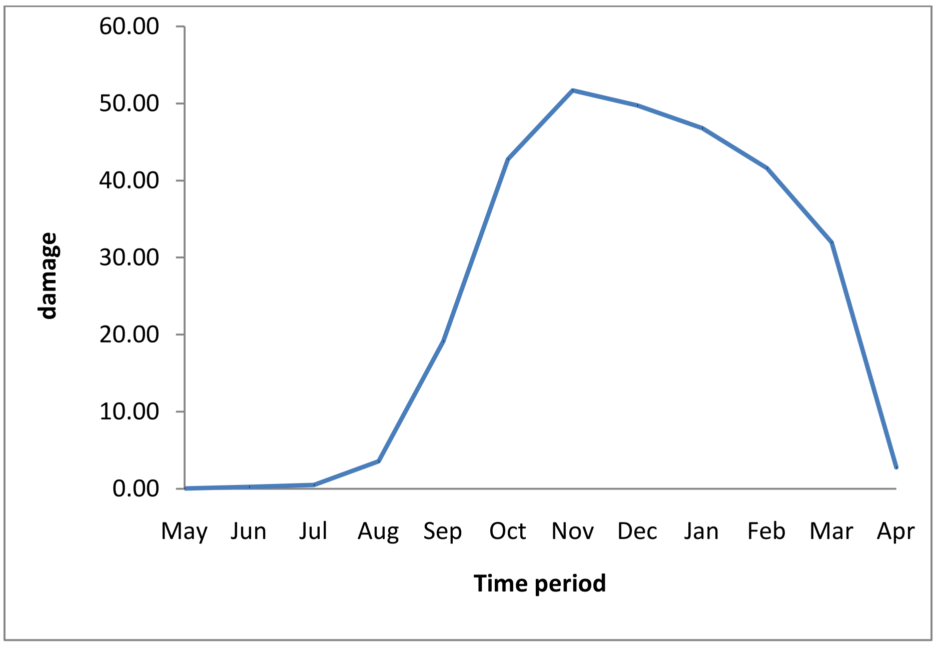


Figure 3-9: Damage Due to Insects (Exponential during the Insect Growth)

The damaged amount in each period can be added to calculate the annual total, which was 386.14 kg. This is a considerable amount of grain lost annually only due to insects, which is forcing the household to lower the consumption at some point.

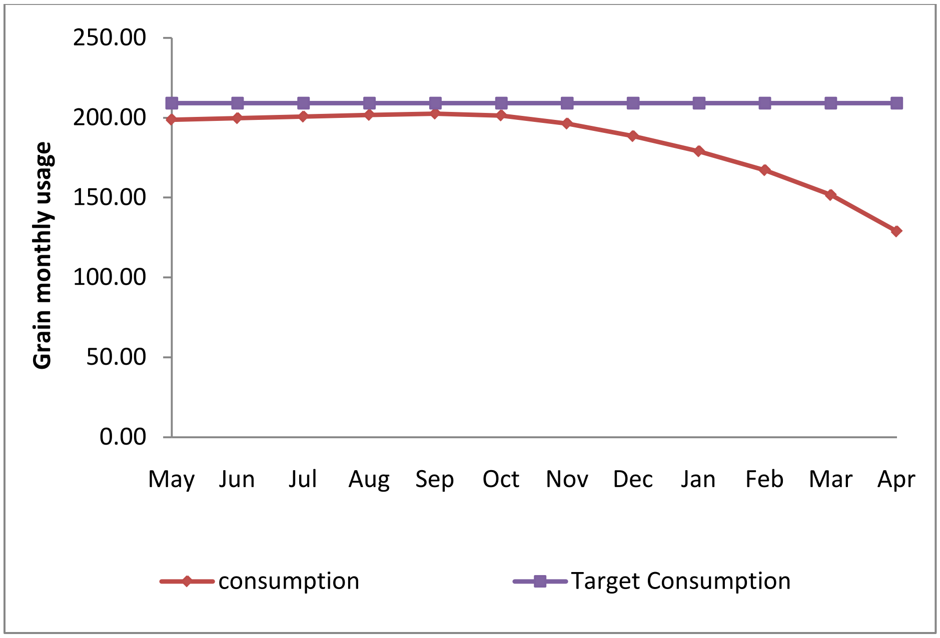


Figure 3-10: Target Consumption and Decreased Consumption after Damages

Understanding the consumption behavior and quantity consumed by household in each period and given the quantity eaten by insects, we can calculate the food deficit in each period using the following equation:

$$F_t = G_0 T^{-1} - C_t$$

Where,

F_t is consumption deficit at period t, G_0 is grain available at the first period, T is total periods, and C_t is consumption at time period t.

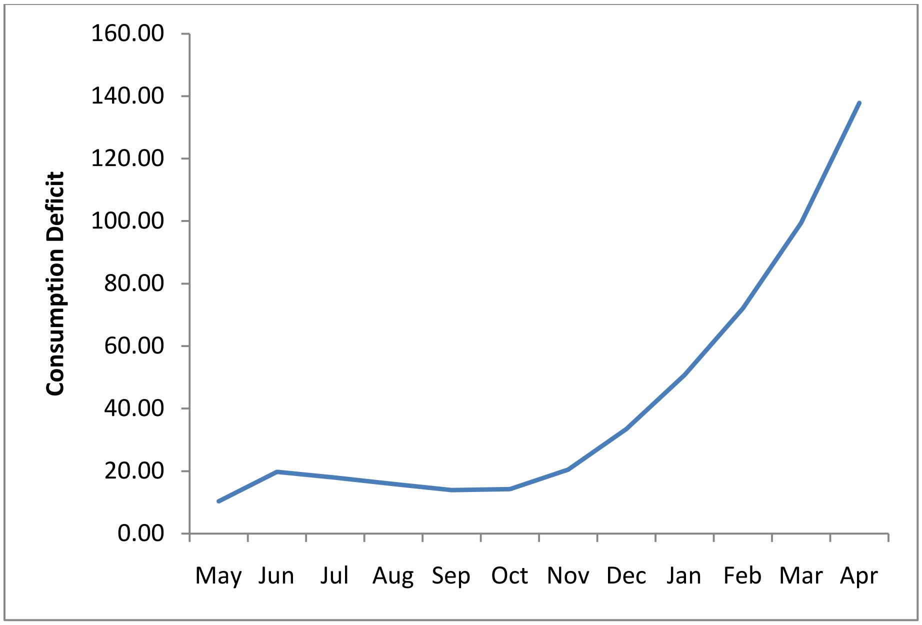


Figure 3-11: Distribution of the Estimated Consumption Deficit

As can be seen from the figure above, the consumption deficit over time is increasing at an increasing rate, indicating the behavior of household consumption given damages due to the insect population. The household is not very responsive to future damages (though conserving grain for future consumption also conserves it for insect use) at the beginning, which is resulting in the higher consumption deficit compared to the starting periods.

Given that we have a consumption deficit in each period, the total deficit in the course of storage can be found using the following equation:

$$F^* = G_0 - \sum_t C_t$$

Where,

F^* is annual deficit, G_0 is grain available at the first period, C_t is consumption at time period t.

It is this notion of a total annual deficit (in an opportunity cost sense we take this value relative to the situation where the household is consuming all grain available) that we will make use of in our analysis with the model.

Beginning with a benchmark situation as described in this model chapter, we vary each of the assumptions that may be impacted by a behavioral change (different consumption of stored grain management) to calculate an elasticity of the consumption deficit. Comparing these elasticities will allow us to understand both which values are most critical to pin down from research based estimates in the model as well as which post-harvest management practices have the highest potential to reduce the consumption deficit. Thus, we are able to answer questions using a linked storage and insect model framework, which point the way forward for future research and education regarding household grain storage.

CHAPTER 4. RESULTS AND SENSITIVITY

As discussed in the previous chapter, the baseline model is based on several assumptions which are known with little certainty and are also subject to changes when behavior changes. Alteration in these assumptions may change the household storage, consumption and loss results considerably. In this chapter, we will discuss how the results change when the assumed values used in the model are altered, in particular values/numbers assumed about the insect multiplicative and growth rate (which may result from storage management interventions), and characteristics of the representative farm household. This will broaden our understandings of the possible outcomes given different situations, as well as indicate the most sensitive assumptions which require further research using primary data from the region.

The changes in the baseline assumptions as well as the results generated from such changes are explored in term of elasticity showing a percent change in consumption deficit with respect to a one percent change in assumed exogenous variable value. Elasticities will measure the first order effects in terms of the changes in each parameter used in the sensitivity analysis.

Table 4-1: Summery Table Elasticities

Shocks	Elasticities	
	+1%	-1%
Number of Eggs	2.79	-2.73
Infestation Level	0.95	-0.96
Mortality Rate	16.52	-14. 81
Consumption Risk	0.96	-0.96

4.1. Sensitivity on the Number of Eggs

Depending on the environmental conditions, the number of eggs each female lays might vary. Additionally, most research reports a range starting at 80 eggs per female at minimum and 200 eggs per female at maximum. This can cause significant changes in terms of the amount of grain damaged and as a result creates significant changes in terms of the outcome of the model.

The number of eggs directly affects the consumption deficit; as the number of eggs per female increases the damage increases, and as a result the consumption deficit is increased and vice versa. Given the baseline assumptions which is 140 eggs per each female and 0.00016 kg damage factor per adult, the sensitivity table (4-1) reports a percentage change in the consumption deficit as a result of one percent change in the number of eggs.

Table 4-2: Sensitivity Table for % Change in Consumption Deficit with Respect to Damage Coefficient (ROWS) and Number of Eggs (Columns).

Scenarios		Number of Eggs		
		138.6	140	141.4
	0.000154	-6.48	-3.86	-1.18
	0.000155	-5.54	-2.89	-0.19
	0.000157	-4.61	-1.93	0.80
Damage	0.000158	-3.67	-0.96	1.80
	0.000160	**-2.73**	**0.00**	**2.79**
Coefficient	0.000162	**-1.80**	0.96	**3.78**
	0.000163	-0.86	1.93	4.77
	0.000165	0.08	2.89	5.76
	0.000166	1.01	3.86	6.75

As can be seen from the table above, the elasticity or percent change in consumption deficit at the baseline is zero, while it changes as the number of eggs increases or decreases. The baseline corresponds with the damage factor of 0.00016 kg per female and 140 eggs per one female. The elasticity or percent change in the consumption deficit (relative to baseline) as a result of a one percent increase and a one percent decrease in the number of eggs is 2.79 and -2.77 respectively. This change in the consumption deficit as a result of a one percent increase or decrease is almost constant or linear shown in the figure (4-1).

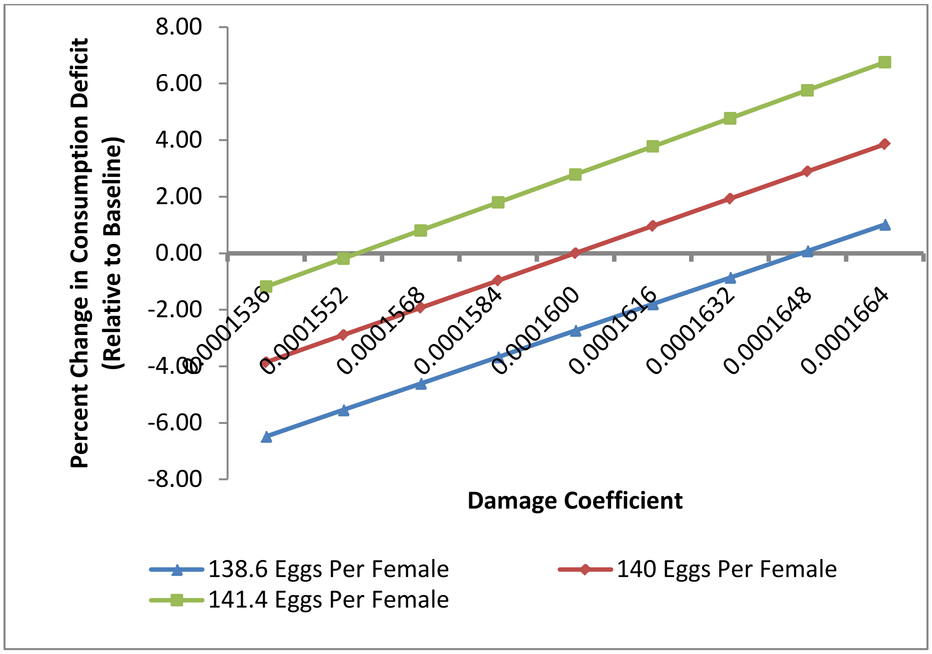


Figure 4-1: % Change in Consumption as a Result of one Percent Change in the Number of Eggs

4.2. <u>Sensitivity to the Infestation Rate</u>

The initial infestation rate or the density of insect population in a particular amount of grain is never constant and can vary. In this study, the baseline assumption about initial infestation is 300 females in the total amount of grain stored. Any deviation from the baseline in terms of the initial infestation rate will change the damage rate, and it will in turn change the total consumption deficit.

Given that the initial infestation level is 300 and the damage coefficient is 0.00016 kg per each adult, table (4-2) shows a one percent change in the consumption deficit as a result of a one percent change from baseline in the initial infestation level. As the initial infestation increases or decreases by one percent, the elasticity or percentage change consumption deficit is 0.96 and -0.96 respectively.

Table 4-3: Sensitivity Table for % Change in Consumption Deficit with Respect to Damage Coefficient (Rows) and Initial Level of Infestation (Columns)

Scenarios		Infestation Level		
		297	300	303
	0.000154	-4.78	-3.86	-2.93
	0.000155	-3.83	-2.89	-1.96
	0.000157	-2.87	-1.93	-0.98
	0.000158	-1.92	-0.96	-0.01
Damage	0.000160	**-0.96**	**0.00**	**0.96**
Coefficient	0.000162	-0.01	0.96	1.94
	0.000163	0.94	1.93	2.91
	0.000165	1.90	2.89	3.88
	0.000166	2.85	3.86	4.86

As shown in the figure (4-2), the percent change in the consumption deficit as a result of change in the infestation level from baseline is constant and linear. This means that given a percentage change in the infestation level, percent increase in consumption deficit is exactly the same as percent decrease in consumption deficit (but negative).

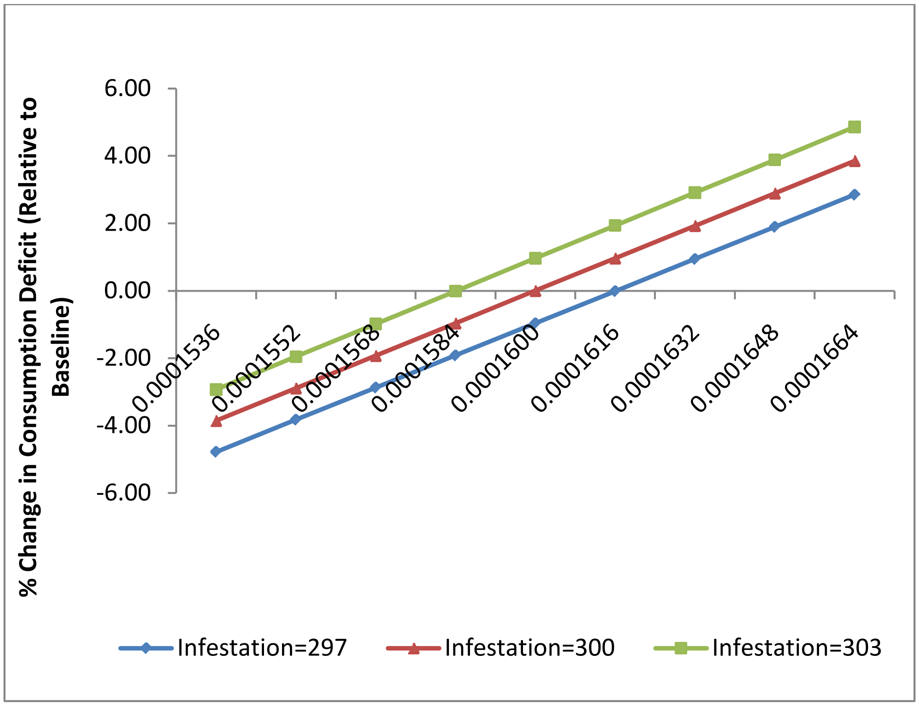


Figure 4-2: % Change in Consumption Deficit as a Result of One Percent Change in Infestation Level

4.3. Sensitivity on Mortality Rate

As discussed in chapter 4, survival rate of insects depends on environmental factors and the overall condition of storage place which may vary. The mortality rate affects the total damage and as a result, changes the total consumption deficit. Given the baseline values of 85% mortality rate and damage coefficient per adult of 0.00016, a one percent increase and decrease in the rate of mortality will change the consumption deficit by 16.51 and -14.81 percent respectively.

Table 4-4: Sensitivity Table for % Change in Consumption Deficit with Respect to Damage Coefficient (Rows) and Mortality Rate (Columns).

Scenarios		Mortality Rate		
		0.8415	0.85	0.8585
	0.000154	12.00	-3.86	-18.07
	0.000155	13.12	-2.89	-17.26
	0.000157	14.25	-1.93	-16.44
	0.000158	15.38	-0.96	-15.63
Damage	0.000160	**16.51**	**0.00**	**-14.81**
Coefficient	0.000162	17.64	0.96	-14.00
	0.000163	18.77	1.93	-13.18
	0.000165	19.90	2.89	-12.36
	0.000166	21.03	3.86	-11.55

The mortality rate has the highest effect on damage rate and convertibly changes the consumption deficit as shown in figure (4-3).

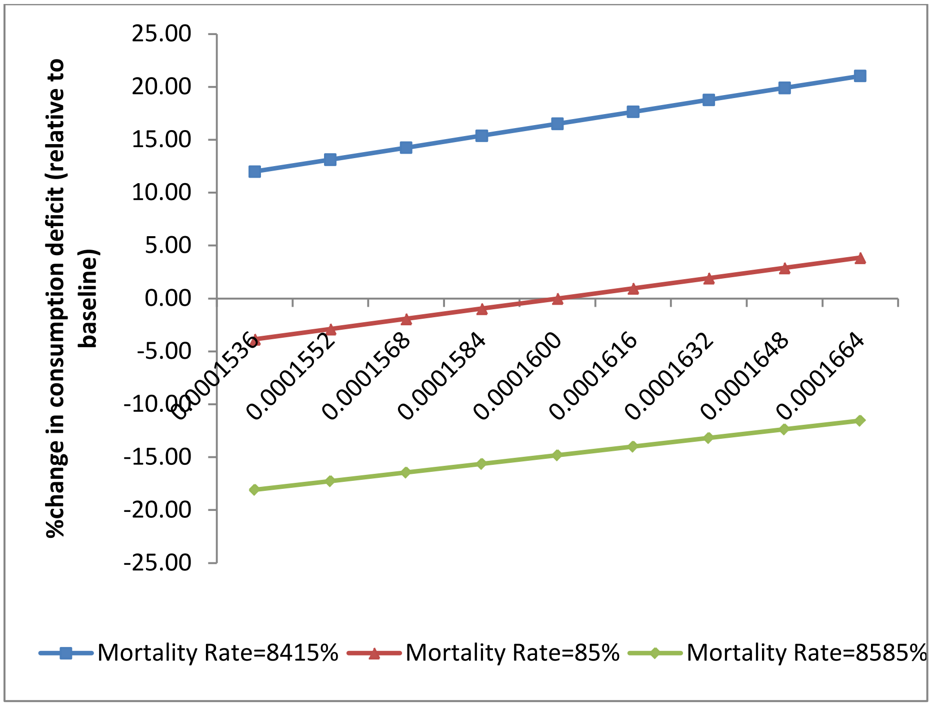


Figure 4-3: % Change in Consumption Deficit as a Result of One Percent Change in Mortality Rate

4.4. Sensitivity on Consumption Risk Factor

As addressed in the perversions chapter, the risk factor is an inter-periodic buffer used in the model to smooth out the consumption path. Since the consumption behavior is different among individual households due different expectation about losses and availability of other grain, the consumption risk factor will vary. More risk averse households try to consume less during the first periods (as they expect more losses in the following periods), whereas less risk averse households are indifferent and do not change their consumption behavior. Therefore, the amount of buffer stored is directly related to the consumption behaviors of individual households and can vary among households.

Assuming the baseline values of 5 percent for the risk factor and 0.00016 kg per adult as the damage coefficient, the table (4-4) reports percentage in the total consumption deficit as a result of one percent changes in the risk factor and damage coefficient.

Table 4-5: Sensitivity Table for Total Consumption Deficit with Respect to Damage Coefficient (Rows) and Risk Coefficient (Columns).

Scenarios		Risk Coefficient		
		0.045	0.05	0.055
	0.000154	-4.30	-3.86	-3.40
	0.000155	-3.33	-2.89	-2.44
	0.000157	-2.37	-1.93	-1.48
	0.000158	-1.40	-0.96	-0.51
Damage	0.000160	**-0.44**	**0.00**	**0.45**
Coefficient	0.000162	0.52	0.96	1.41
	0.000163	1.49	1.93	2.38
	0.000165	2.45	2.89	3.34
	0.000166	3.42	3.86	4.31

The consumption deficit is not considerably responsive to changes in the risk factor (figure 4-4). This is because the total expected damage is higher than the 5% buffer and the buffer cannot account for the all of the loss.

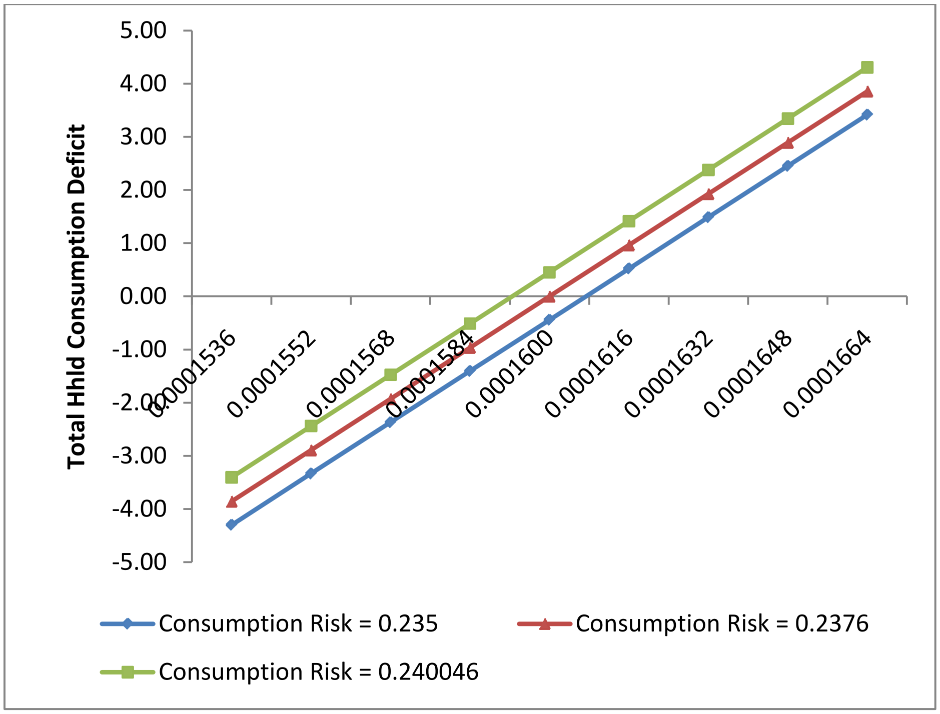


Figure 4-4: % Change in Consumption Deficit as a Result of One Percent Change in Consumption Risk

4.5. Summary of Elasticities

Referring to the table 4-1 which lists the elasticities (a percent change in consumption deficit with respect to a one percent change in assumed exogenous variable value), it can be noticed that mortality rate has the highest effect (in term of percent change in consumption deficit) on consumption deficit. Given that mortality rate or survival rate directly affects the insect multiplication (i.e. as a result of one percent decrease in survival rate, total population decreases by 185 adults), leading to a considerable fall in consumption deficit (16.7% or 57.6kg). Number of eggs has the second largest affect on the consumption deficit (i.e. as a result of one percent decrease in the number of eggs, total population decreases by 34.4 adults) causing the total consumption deficit to fall by 2.77% or 11.6 kg.

Damage coefficient and infestation level have the same affect on consumption deficit. As in the table 4-1, decreasing both the damage coefficient per adult and infestation level decreases consumption deficit by 0.97% or 3.74kg, however, they do not affect the multiplicative rate and total insect population. Referring to the damage equation in chapter 3, both the damage coefficient per adult and the infestation level are included in the equation and multiplied with each other to calculate the damage (thus to calculate the consumption deficit); therefore, they have equal effect on the consumption deficit (same elasticity). The consumption risk factor has the smallest (one percent increase in consumption risk could increase the consumption deficit by effect on the total consumption deficit, by 0.15%). Although it has small affect on consumption deficit it has considerable impact on the household consumption pattern during the year.

Understanding the elasticities allows us to comprehend the effect of potential storage interventions. Depending on the specific intervention strategy, the mortality rate or the number of eggs per adult can be influenced, leading to substantial changes in the total insect population, the damage rate, and thus consumption deficit.

Given the elasticities and that each storage intervention has different effects, the S.L.A.M and triple bag strategies affect exogenous parameters (i.e. number of eggs, mortality rate) differently (although the final target is one and that is to prevent damages). S.L.A.M management strategy (as it stands for sanitation, loading, aeration and monitory) is more preventative and its application manages the insect population or the insect multiplication in first place (i.e. reduces the number of eggs). On the other hand, triple bag storage intervention targets the mortality rate (increases the mortality) and, as a result fewer insects survive and complete the life cycle resulting in the decreased insect population. Other storage intervention, fumigation, is another example of the intervention management which kills insects (increases the mortality).

This gives us an idea of the appropriate storage intervention type at a right time. Depending on the intervention type and time, triple bag or S.L.A.M strategies can be applied to reduce the insect population, thus to reduce the consumption deficit. To evaluate which storage management strategy or intention is appropriate and to assess its economic impact requires further research and systematic data on the grain storage systems, the insect growth properties, the pattern of damages and the household consumption behaviors.

4.6. Implications of Consumption Risk Factor

One way to view the model is to consider different behavior circumstances that households might adopt when they are able to forecast the damaged and lost grain due to insects. To do this, we consider larger changes in the risk consumption coefficient, while assuming that insect infestation and damage occurs at baseline rates

As mentioned earlier, the consumption risk factor will not change consumption deficit noticeably; however, it greatly can change the consumption path during the year (as its main aim in the model is to smooth out the consumption pattern). We will look at the effect of consumption risk on the household consumption behavior in the following three scenarios:

4.7. Scenario One (Baseline Scenario)

The baseline scenario is based on the baseline model assumptions which will use a 5% level of buffer and the damage coefficient of 0.00016 kg per adult female. Figure 4-5 shows the responsiveness of household to losses and its consumption behavior at the baseline scenario given the target consumption. As the consumption deficit increases, the amount consumed is decreased relative to the target consumption level.

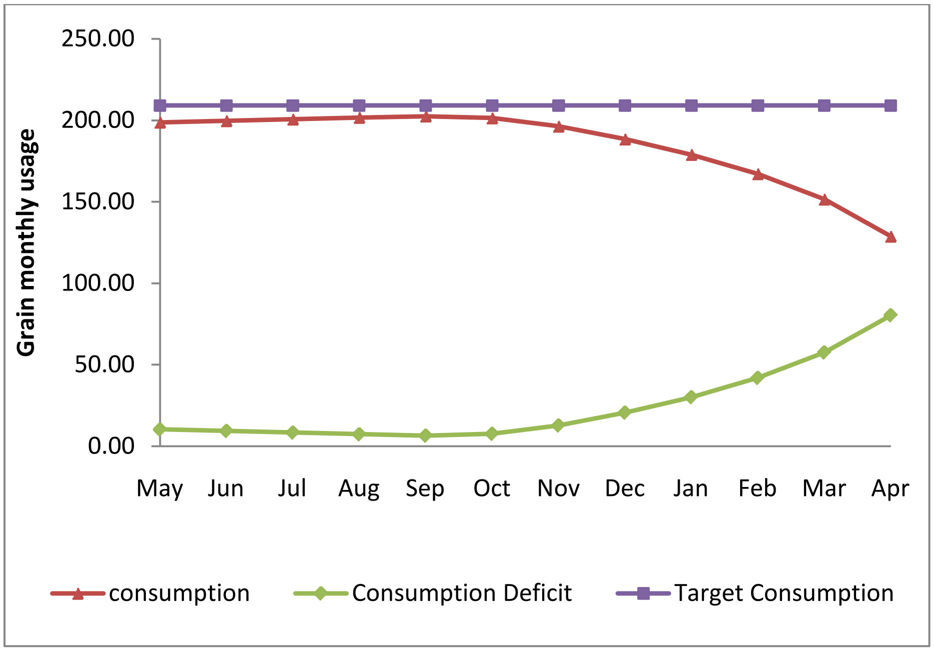


Figure 4-5: Sensitivity to Consumption Risk (Baseline Scenario)

The household corresponding to the baseline scenario is not risk averse and does not adjust the consumption level during the year. They consume almost at the target level during the first periods with decreases later and finally running out of stock at the end of the year. As the household runs out of the grain (in April) the consumption line and the consumption deficit line cross each other. The area between the target consumption line and the consumption line is the amount lost during 12 periods of storage and is equal to the area below the consumption deficit line.

4.8. Scenario Two (Higher Risk Coefficient)

This scenario is based on a higher risk factor given the baseline assumption of the damage coefficient. The household corresponding to this scenario stores a higher amount of buffer, expecting the same amount of loss as in the baseline scenario. Value used for the risk factor is 25% of buffer. As shown in the figure 4-6, the consumption path is smooth and the household consumes almost less in the first periods keeping the grain for later periods. The household corresponding to this scenario is more risk averse, expecting higher losses and therefore storing more grain as buffer compared to the baseline.

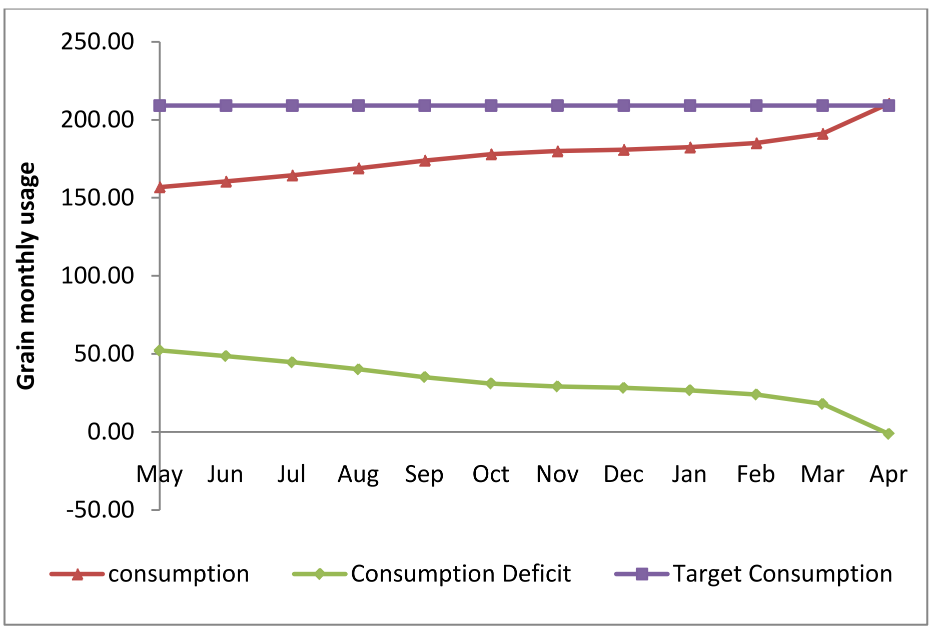


Figure 4-6: Sensitivity to Consumption Parameter Given Higher Risk Coefficient (Relative to Baseline)

The consumption line and the consumption deficit lines are almost horizontal, showing a steady consumption over the year. The two lines do not cross indicating the household still has grain in the storage place and does not run out of stock till the end of the last period (April).

4.9. Scenario Three (Higher Consumption Risk and Higher Damage Coefficient)

In this scenario, both the consumption risk and the damage factor are higher relative to the baseline scenario. In this situation we will notice the effect of higher expected damages given the same amount of buffer stored as the in the second scenario. The values chosen for the damage coefficient and consumption risk factor are 0.0003 (approximately doubled) and 25 percent respectively.

In this situation the amount lost due to insects is greater than the amount of buffer stored, which cannot cover the damages, and the household runs out of the stock regardless the level of consumption (even though the household is very risk averse) as shown in the figure 4-7.

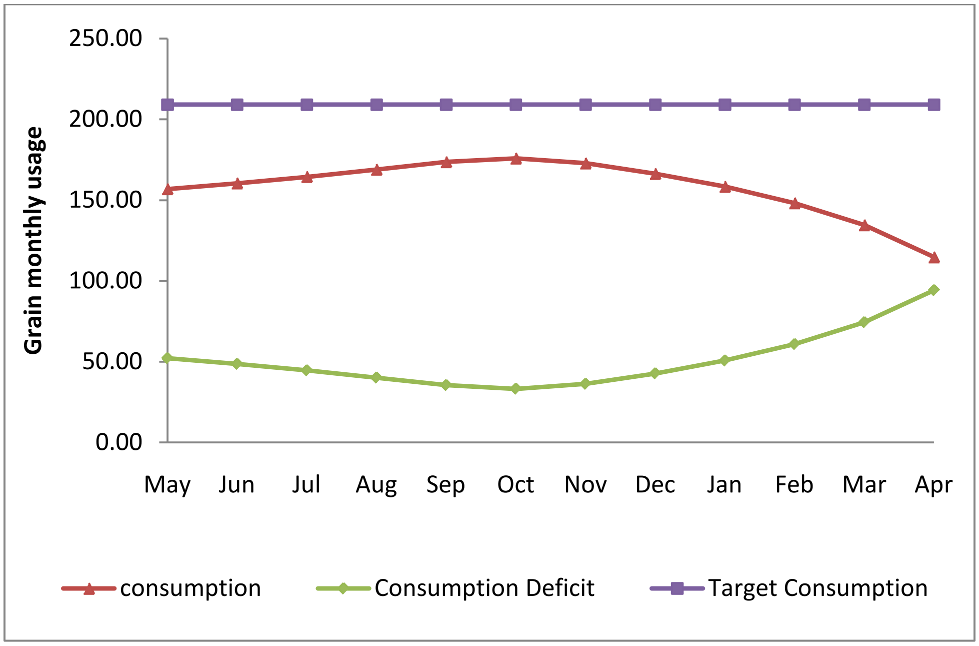


Figure 4-7: Sensitivity to Consumption Risk with a Higher Damage Coefficient (Relative to Baseline)

The consumption deficit is higher and is increasing rapidly in the later periods, causing the household to run out of stock as the consumption line and the consumption deficit line cross each other indicating the household runs out of grain as the last period starts.

4.10. Importance of Understanding Consumption Risk and its Timing

Given the expected losses during the year, households must adjust their consumption paths. In places where the households have limited access to market during different seasons of the year, in particular winter, it becomes increasingly important to account for expected losses, adjust consumption in the early periods and avoid running out of food in the later periods.

Additionally, consumption behavior and the consumption timing should be considered if the household introduces management intervention. More grain is consumed during the early periods or holding back on consumption in early periods will affect the timing of management interventions application.

CHAPTER 5. CONCLUSION AND FINDINGS

In Afghanistan, wheat is core to food security and poverty reduction. Lack of appropriate grain storage facilities and better management practices are causing food shortages which undermines food security. One way to overcome the problem is to make the best use of what is produced which starts with post harvest processing and storage. The amount of wheat consumed by the household is considerably less than the amount produced .Much of this gap could be covered with better post harvest processing. Thus, it is important to find ways and means of reducing the potential heavy losses of the food grain at the post harvest stage due to poor management and inadequate storage facilities. In this chapter we will discuss conclusions based on the results that were presented in the previous chapters.

5.1. Use of Storage Intervention

Given the elasticities which measure the percent of changes in total consumption deficit as a result of changes in the exogenous variables, we can utilize any storage intervention to modify the insect population resulting in reduced total storage damage, and evaluate its implications on the household food availability. Assuming that storage intervention will target to reduce the estimated total insect population to a modified economic threshold, we can estimate saved losses on the household level as well as on a community or regional level (if the same storage intervention are applied and practiced).

Depending on the total insect population and the damage due to it, the economic threshold level will vary. This can be determined using precise data on the insect population, damage rate or the total loss, and the household perceptions about current losses and grain quality. For simplicity we provide a hypostatical example assuming that household uses storage intervention which results in increased mortality rate, thus decreased total population. Suppose Mortality rate as a result of storage intervention goes up by 5%. Figure 5-1 shows effect of storage intervention on the total estimated population, assuming the mortality rate increases from 85% (baseline assumption) to 90%. After imposing this change on the baseline model, the estimated consumption deficit is 100.33 kg.

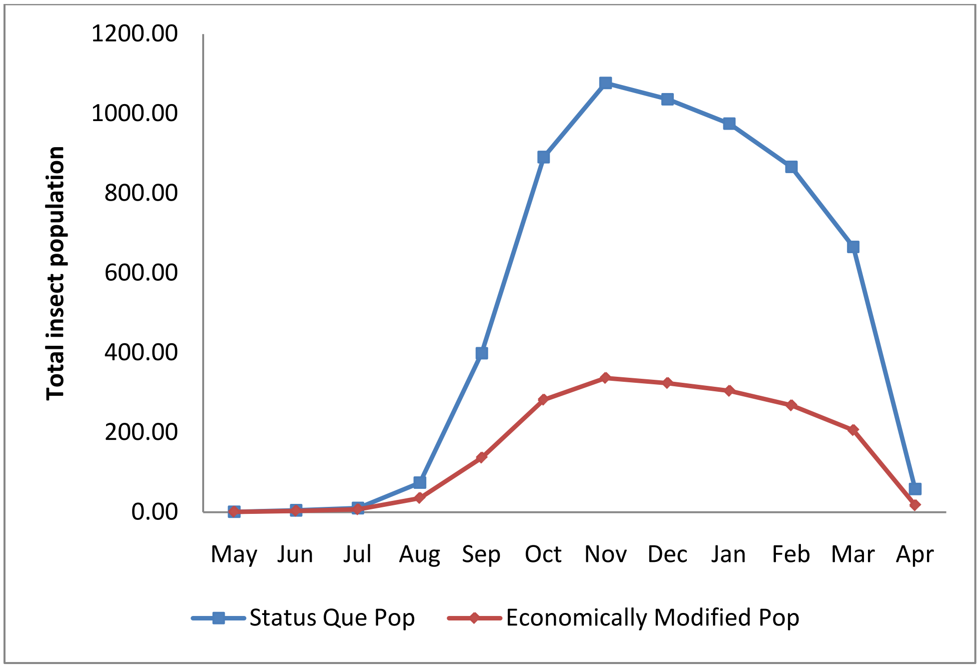


Figure 5-1: Drop in Insect Population as a Result of Projected Intervention

Understanding the drop off in total population, we can derive the pattern of savings as a result of storage intervention, which reduces the total population and damages (figure 5-2).

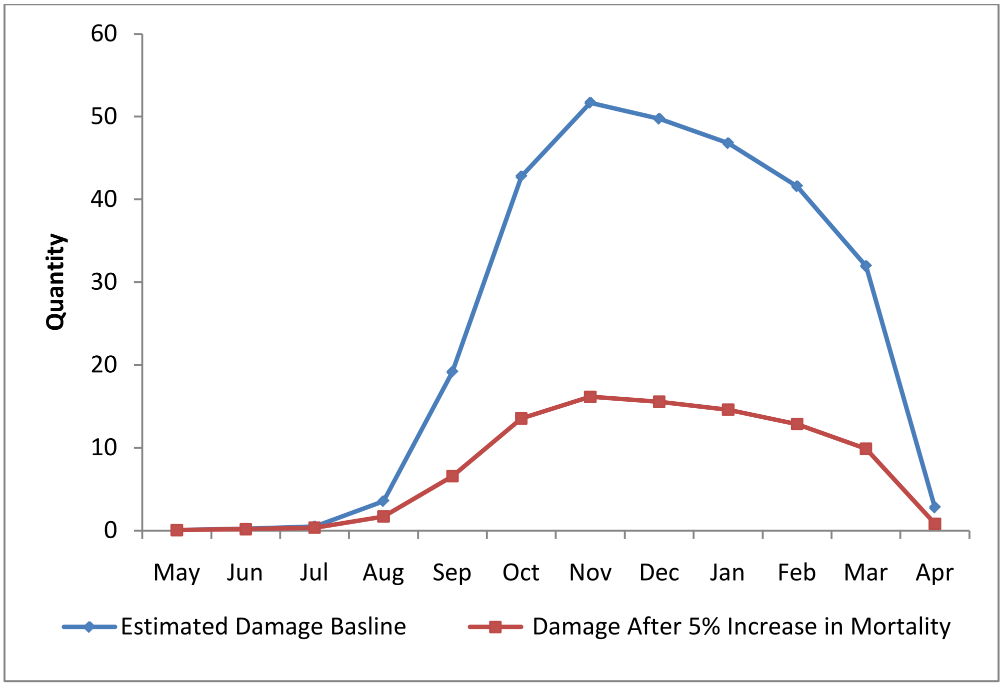


Figure 5-2: Reduction in Damage as a Result of Projected Storage Intervention

As the decreased damage is now obvious, we can calculate the total saving as a result of the storage intervention for the household. Extending this, we can assess the implication of storage intervention on a regional level, assuming the same technology or the management practice was used as a storage intervention.

5.2. Food Security Consideration

As argued in the previous chapters, for small farmers as in Afghanistan the main purpose in storing grains is to ensure household food supplies. At the same time as discussed earlier, the storage model is built based on the grain requirement to supply required grain for a year for the household, which accounted for the expected losses as well. Given the estimated losses from the model and using the actual harvest amount as the initial quantity to be placed in storage, we can evaluate the household food security and present the results. This will allow us to connect the model to the household production and to discuss its implication on food security.

The harvest quantity is less than the planned quantity (which is based on the total storage requirement) to be stored for one year:

$$G_0= X^* Y$$

Where G_0 is the initial quantity stored, X is area planted in wheat in hectare which is (which is assumed to be 1.75 hectares), and Y is the average yield per hectare. The average yield reported since 1980 is 1225 kg per hectare and the total amount based on this yield and area a representative household harvests is 2143.75kg. Using the precise quantity harvested (2143.75kg) as initial amount of stored quantity, the estimated consumption deficit is 658 kg which is much higher. Given the estimated losses, this higher consumption deficit indicates that the household does not harvest and store enough for the course of the year and must plan on storing extra grain accounting for estimated losses. Additionally, most households are not aware of proper post-harvest losses to adjust their consumption behaviors and may not store enough buffer stocks leading to food shortages along the year.

To make the best use of harvested grain and to ensure food availability and household food security, on-farm storage systems and technologies, management practices and transport system must be improved. Efficient on-farm processing (drying, cleaning, grading) facilities should also be established where households could meet their own requirements.

5.3. Summery

The analysis used in this thesis can be used to estimate the grain savings and impact on household food availability and food security attributable to a specific management practice that reduces insect population. This study provides a framework for future directions concerning potential gains from improved storage facility and management practices.

One of the most important finding from the sensitivity of the model is that increasing mortality rate is the most efficient way to reduce storage losses due to insects. This valuable information should be tested in Afghanistan using more precise data and information on grain production and harvest, storage facility and management practices, reliable data on post-harvest losses and key factors causing such losses including insects.

Key observation is outlining the data requirements for modeling household storage and consumption management, in addition to research on improving productivity, primary research in Afghanistan needs to focus on identifying the relevant values for post-harvest loss so that cost-benefit measures for intervention policies and education programs can be determined more precisely.

Summarizing the analysis, we can clearly propose that decreased wheat storage losses leading to increased food availability and household income leading to poverty reduction, healthier lives, and better education opportunities for the households in Afghanistan.

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APPENDICES

Appendix A. Traditional Storage System Mud-Bins

Photos taken by Kevin McNamara, Professor of Purdue Agricultural Economics

Appendix B. Traditional Storage Systems-Storage Bags

Photos taken by Kevin McNamara, Professor of Purdue Agricultural Economics

Appendix C: Baseline Model Output

Output-Baseline								
Periods (May-April)	Grain Available Start	Consumption	GDD cumulative	Total Insects	Actual Damage Grain	Grain available end	Consumption Deficit	Target Consumption
1.00	2510.86	198.78	388.50	1.00	0.05	2312.04	10.33	209.11
2.00	2312.04	199.68	978.00	4.64	0.22	2112.14	9.43	209.11
3.00	2112.14	200.65	1645.50	10.20	0.49	1911.00	8.46	209.11
4.00	1911.00	201.72	2286.00	73.94	3.55	1705.73	7.39	209.11
5.00	1705.73	202.56	2785.50	399.06	19.15	1484.02	6.55	209.11
6.00	1484.02	201.40	3120.00	891.13	42.77	1239.84	7.71	209.11
7.00	1239.84	196.31	3255.00	1076.81	51.69	991.85	12.80	209.11
8.00	991.85	188.45	3255.00	1036.29	49.74	753.65	20.66	209.11
9.00	753.65	178.99	3255.00	974.76	46.79	527.87	30.12	209.11
10.00	527.87	167.16	3255.00	866.38	41.59	319.13	41.95	209.11
11.00	319.13	151.59	3322.50	665.63	31.95	135.59	57.52	209.11
12.00	135.59	128.81	3571.50	57.88	2.78	4.00	80.30	209.11
					292.77		293.23	2509.32

Appendix D: Scenario Two-High Consumption Risk Factor of 0.25

Output- Consumption risk 0.25								
Periods (May-April)	Grain Available Start	Consumption	GDD cumulative	Total Insects	Actual Damage Grain	Grain available end	Consumption Deficit	Target Consumption
1.00	2510.86	156.93	388.50	1.00	0.05	2353.88	52.18	209.11
2.00	2353.88	160.49	978.00	4.73	0.23	2193.17	48.62	209.11
3.00	2193.17	164.49	1645.50	10.42	0.50	2028.18	44.62	209.11
4.00	2028.18	169.01	2286.00	75.78	3.64	1855.53	40.10	209.11
5.00	1855.53	173.96	2785.50	410.38	19.70	1661.87	35.15	209.11
6.00	1661.87	178.06	3120.00	920.59	44.19	1439.63	31.05	209.11
7.00	1439.63	179.95	3255.00	1119.45	53.73	1205.94	29.16	209.11
8.00	1205.94	180.89	3255.00	1087.47	52.20	972.85	28.22	209.11
9.00	972.85	182.41	3255.00	1038.68	49.86	740.58	26.70	209.11
10.00	740.58	185.15	3255.00	950.91	45.64	509.79	23.96	209.11
11.00	509.79	191.17	3322.50	792.42	38.04	280.59	17.94	209.11
12.00	280.59	210.44	3571.50	289.41	13.89	56.25	-1.33	209.11
							376.37	2509.32

Appendix E: Scenario Three-High Consumption Risk (0.25) and Higher Damage Factor (0.003kg per Adult)

Output- Consumption risk of 0.25 and damage coefficient 0.0003								
Periods (May-April)	Grain Available Start	Consumption	GDD cumulative	Total Insects	Actual Damage Grain	Grain available end	Consumption Deficit	Target Consumption
1.00	2510.86	156.93	388.50	1.00	0.09	2353.84	52.18	209.11
2.00	2353.84	160.49	978.00	4.73	0.43	2192.93	48.62	209.11
3.00	2192.93	164.47	1645.50	10.42	0.94	2027.52	44.64	209.11
4.00	2027.52	168.96	2286.00	75.78	6.82	1851.74	40.15	209.11
5.00	1851.74	173.60	2785.50	410.38	36.93	1641.20	35.51	209.11
6.00	1641.20	175.84	3120.00	920.59	82.85	1382.51	33.27	209.11
7.00	1382.51	172.81	3255.00	1119.45	100.75	1108.94	36.30	209.11
8.00	1108.94	166.34	3255.00	1087.47	97.87	844.73	42.77	209.11
9.00	844.73	158.39	3255.00	1038.68	93.48	592.86	50.72	209.11
10.00	592.86	148.22	3255.00	950.91	85.58	359.06	60.89	209.11
11.00	359.06	134.65	3322.50	792.42	71.32	153.10	74.46	209.11
12.00	153.10	114.82	3571.50	289.41	26.05	12.23	94.29	209.11
							613.80	2509.32

Appendix F: Model Output as Mortality Rate Increased By 5%

Output-Mortality rate increased from 85% to 90%									
Periods (May-April)	Grain Available Start	Consumption	GDD cumulative	Total Insects	Actual Damage Grain	Grain available end	Consumption Deficit	Target Consumption
1.00	2510.86	198.78	388.50	1.00	0.05	2312.04	10.33	209.11
2.00	2312.04	199.68	978.00	3.40	0.16	2112.20	9.43	209.11
3.00	2112.20	200.66	1645.50	7.10	0.34	1911.20	8.45	209.11
4.00	1911.20	201.74	2286.00	35.45	1.70	1707.76	7.37	209.11
5.00	1707.76	202.80	2785.50	136.68	6.56	1498.40	6.31	209.11
6.00	1498.40	203.35	3120.00	282.13	13.54	1281.51	5.76	209.11
7.00	1281.51	202.91	3255.00	336.67	16.16	1062.44	6.20	209.11
8.00	1062.44	201.86	3255.00	324.00	15.55	845.02	7.25	209.11
9.00	845.02	200.69	3255.00	304.24	14.60	629.73	8.42	209.11
10.00	629.73	199.41	3255.00	267.87	12.86	417.46	9.70	209.11
11.00	417.46	198.29	3322.50	205.80	9.88	209.29	10.82	209.11
12.00	209.29	198.82	3571.50	17.15	0.82	9.64	10.29	209.11
							100.33	2509.32