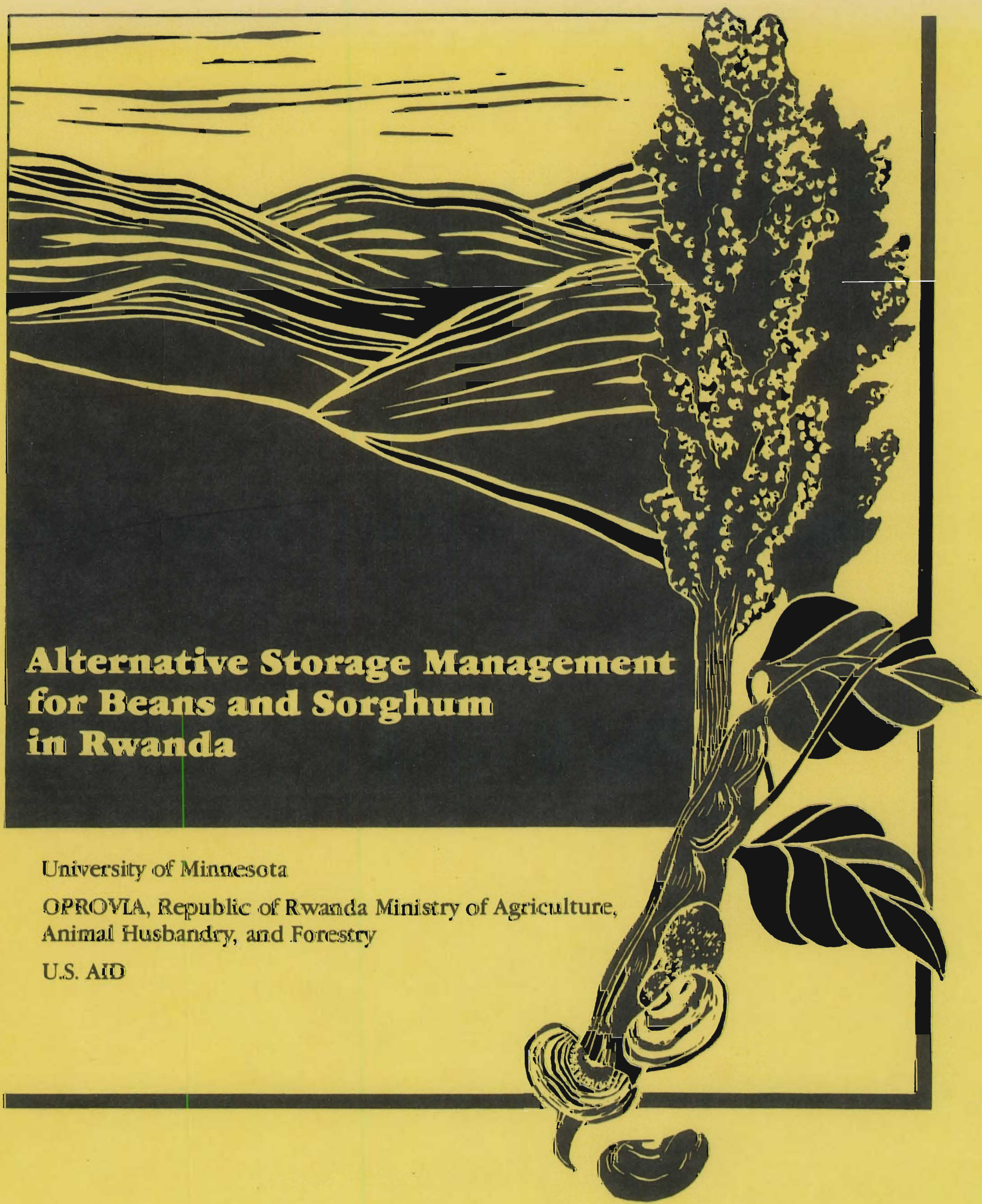

Alternative Storage Management for Beans and Sorghum in Rwanda

University of Minnesota

OPROVIA, Republic of Rwanda Ministry of Agriculture,
Animal Husbandry, and Forestry

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EXECUTIVE SUMMARY

The objectives of this phase of the project were to: 1) evaluate characteristics of storage methods and conditions for beans (Phaseolus vulgaris) and sorghum (Sorghum bicolor) in Rwanda, 2) develop appropriate alternatives for each level of storage, 3) test and evaluate these alternatives, 4) develop a system for rapid detection of storage problems, and 5) train Rwandan technicians in storage methods.

The present storage situation at OPROVIA/GRENARWA, cooperative and producer levels is described in terms of storage structures, handling and problems encountered (Chapter 2). A series of experiments directed toward the problems at these storage levels were undertaken. Underground storage experiments were also carried out.

At the OPROVIA/GRENARWA (warehouse) level (Chapter 4) beans and sorghum are stored in bags. Temperatures were monitored in aerated and non-aerated bag piles. Obtaining uniform temperatures in aerated bag piles proved to be difficult because of nonuniform airflow distribution. Temperature measurements in the non-aerated pile indicated higher temperatures at the top than at the bottom. This is likely a result of heat load on the roof. Results of an experiment to evaluate the potential effect of roof insulation suggested that including a layer of insulation under the roof along with improved roof ventilation could significantly lower roof temperatures and, therefore, temperatures of the warehouse interior during the daytime hours.

Plans were developed for ambient air drying of beans destined for long-term (longer than one year) storage. Ambient air drying fits well with the climatic conditions and energy resources of Rwanda. Experiments involving 1) effectiveness of aeration in bulk storage in retarding the development of insects and 2) the resistance of different bag materials (jute, woven plastic and polyethylene plastic sheet) to insect penetration were started. These experiments provided a good opportunity for Rwandan staff to design and carry out storage experiments.

The experiment involving monitoring of bag piles showed that damage levels were already high for beans going into storage. Procedures to evaluate quality as beans and sorghum are received with the option of segregating by quality and of cleaning to improve quality should be considered.

Future work at the warehouse level should focus on solutions to handling problems including existing bottlenecks in receiving, treating and rebagging as well as needs arising from projected increased activities in cleaning and drying.

At the cooperative level (Chapter 5), beans and sorghum are stored at silos in bulk compartments (12-15 metric tons each) and at hangars (sheds), preferably in bags stacked on pallets. Experiments involving monitoring of temperatures in non-aerated and aerated silos showed that the silos provide good thermal protection for the stored product. Therefore, there is little advantage for aeration in these relatively small compartments.

The design of the silo compartment makes it difficult to monitor the product during storage. Modifications to facilitate monitoring are currently under evaluation. Likewise, a manually operated auger system shows promise for improving unloading of silo compartments.

Well-designed, well-managed cooperative silos provide good storage conditions. The problems observed have been associated with poor construction and poor site selection. Poor management resulting from the rapid turnover and inadequate training of silo managers is a significant problem.

Hangar (shed) storages at the cooperative level are suitable for storage in bags on pallets although they provide less natural protection against rodents and greater risks with fumigation for insect control. Hangars are not suitable for storage in bulk due to poor vapor barriers in floors and walls.

At the producer level (Chapter 6), bean storage experiments involving traditional containers (small, medium, large and very large baskets, clay pots, imbohos and exterior granaries) and alternative containers (metal and plastic drums) were carried out. A high degree of variability was found in the results with no obvious storage advantage exhibited for any one of the traditional containers over another. The alternative containers had high resistance to moisture (vapor) movement. As a result there was little change in moisture content during storage with the alternative containers compared to the traditional containers. This means it is important to have beans dry when they are put into the alternative containers since wet beans will not lose moisture as they do in traditional containers. The alternative containers also can potentially achieve airtight storage conditions. The results showed that this feature was apparently providing control of insects in the alternative containers. Recommendations for further development and testing of alternative containers for producer level storage are included.

Underground storage experiments (Chapter 7) in groups (8 or 11) of 90 kg bags of beans were conducted. Results of a one-year experiment starting with good quality beans are available. Partial results of a two-year experiment starting with poor quality insect infested beans are also included. The underground experiments have been technically successful; however, special management is needed in building the pits and sealing the bags. Furthermore, grain monitoring is difficult or impractical.

Underground storage appears to be most applicable to long-term storage. The creation of an airtight environment has advantages for control of insects. Another potential advantage, yet to be confirmed, is maintenance of bright color (new bean appearance). However, further work is needed before widespread use of this technology is recommended in Rwanda.

A set of conclusions and recommendations (Chapter 8) are presented--both general and by storage level. The major conclusion is that management is the single most important aspect to improving storage at all levels in Rwanda. Management includes a) assessing quality going into storage, b) monitoring quality throughout storage and c) taking corrective action where necessary.

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1. INTRODUCTION

Beans (*Phaseolus vulgaris*) are the major source of vegetable protein in the Rwandan diet. Total production in 1984 was 256,000 metric tons (MT) (MINAGRI, 1985). Beans are produced in two crops each year with the December-January harvest yielding the major production and the June harvest a lesser amount.

Beans are stored, primarily in large baskets, for seed and food by farmers between harvests. An estimated 30 percent of the production is marketed, usually at the local level. Beans are marketed through merchants, storage cooperatives and a government marketing organization called OPROVIA/GRENARWA.

Sorghum (*Sorghum bicolor*) is the most important cereal crop grown in Rwanda. One crop is produced each year and most is harvested during June and July. Estimated production in 1984 was 171,000 MT (MINAGRI, 1985). Sorghum is primarily stored in baskets as with beans, although some of the crop is stored unthreshed (panicles) in exterior granaries. Sorghum is also marketed through merchants, storage cooperatives and OPROVIA/GRENARWA.

A storage survey of beans and sorghum in Rwanda found that total damage due to mold, insects, rodents, etc. was lowest at the farm storage level (Dunkel et al., 1986). The highest levels of damage were found in the OPROVIA/GRENARWA warehouses with intermediate levels observed at the cooperative level. These results are consistent with observations of others familiar with storage at these levels.

There are several potential reasons why the higher levels of damage were observed in the cooperative and warehouse storages. These include:

1. The interval of time after harvest is greater for beans stored at the cooperative and warehouse levels than at the farm level. The longer interval between harvest and utilization results in greater potential for damage.

2. The quantities stored at an individual location are greater and, therefore, harder to monitor at the cooperative and warehouse levels than at the farm level. Thus, different types of storage structures and management techniques are required.

3. Farmers are likely to use the higher quality beans and sorghum for food or seed and, therefore, market beans and sorghum with higher damage levels. Therefore, the quality of beans and sorghum entering the cooperative and warehouse level storages is likely to be lower than at the farm level storages. Furthermore, neither OPROVIA nor the cooperatives offer price incentives to reward delivery of higher quality beans or grain.

These results point to a need for work on alternative storage methods and management procedures--particularly at the cooperative and warehouse levels--to attempt to reduce damage and losses.

An additional problem encountered in storing beans is the development of a condition referred to as 'hard-to-cook'. The 'hard-to-cook' condition becomes more severe with time and is accelerated by storage at higher temperatures and higher moisture contents. Since OPROVIA/GRENARWA often receives beans several months after harvest and stores them for up to one year, the development of the hard-to-cook problem is significant.

The Government of Rwanda is also considering establishing a strategic security stock for beans to guard against periods of low production. These beans would be stored for 2 or 3 years; thus development of the hard-to-cook problem could be potentially very significant if appropriate storage management practices were not used.

For these reasons, the alternative storage management component was included as part of the research activities of the Food Storage and Marketing Project (FSM II). The goal of the total project is to improve storage and marketing of beans and sorghum in Rwanda.

The objectives of the alternative storage management component as stated in the final work plan (June 1985) are to:

1. Evaluate the characteristics of the storage methods and conditions identified during previous storage surveys conducted at the producer, cooperative and GRENARWA levels.

2. Develop appropriate storage alternatives for each level based on the preceding evaluation.

3. Test and evaluate these new methods in order to make recommendations.

4. Develop a system of rapid detection of storage problems, especially for cooperatives and GRENARWA.

5. Train Rwandan technicians in storage methods, technical operation of storage centers, and maintenance of storage and research equipment.

This report begins with a description of the present situation. Procedures used to evaluate quality of beans and sorghum are then explained. Experiments and results are discussed by storage level--warehouse, cooperative and producer. Experiments involving underground storage, a technique not previously used in Rwanda, are then described. Finally recommendations and suggestions for further study are presented.

2. PRESENT SITUATION

2.1. OPROVIA/GRENARWA Level

2.1.1. Structures

The OPROVIA/GRENARWA organization operates about 25 large and small warehouses or 'godowns' throughout the country, including those that are constructed for the storage of food aid and the strategic food reserve, with a total storage capacity of more than 26,550 metric tons (MT). The storage capacity per warehouse ranges from 200 to 3,750 MT. The layout and design are very similar for most of these government-owned buildings, but their actual size depends on local storage needs. The one major exception is the warehouse in Nyanza (3,000 MT). While all other warehouses are brick buildings, this one is a metal hangar which was originally built as a coffee handling and storage facility. They are all used exclusively for bag storage.

The main storage center is located at OPROVIA's headquarters in Kicukiro (Fig. 2.1), a suburb of Kigali, and consists of three large warehouses of similar design: OPROVIA (3,750 MT), GRENARWA (2,500 MT) and World Food Program (2,500 MT). A 3,000 MT addition to the GRENARWA warehouse has recently been completed for the storage of the strategic food reserve. A description of the GRENARWA warehouse, where most of the research work was conducted, is given below. Descriptions of other typical warehouses located elsewhere in the country can be found in Dunkel et al. (1986).

The GRENARWA warehouse in Kicukiro is located at an altitude of 1,495 m and is constructed on a sloping piece of land. The rectangular building (50.3 x 26.0 m) houses a large storage area (45.0 x 26.0 m), a supply room (5.3 x 20.8 m) and an office (5.3 x 5.2 m). The general layout of the building is shown in Fig. 2.2. The floor consists of a layer of reinforced concrete resting on a layer of sand covering a rock foundation. A moisture barrier (0.3 mm plastic sheeting) is placed between the sand and the concrete layers. The kiln-dried clay brick walls are 5.00 m high and 0.20 m thick. They are covered on the interior side with a layer of cement plaster and whitewashed. The walls are reinforced with a welded frame construction consisting of I-shaped steel posts, spaced 5.0 m apart, and a steel bond beam. Two claustra (ventilation openings) are installed at 0.4 m above the floor level in each 5.0 m wall section of the long sides of the building. They each cover an area of 0.20 x 0.80 m of which 35% are openings. They are covered on the outside with fine meshed metal insect screens.

Two gable frame roof sections cover each one half of the storage area. They have a span of 13.0 m and support a roof made of metal sheeting. Some of the metal panels have been replaced with translucent plastic ones. The trusses are constructed in such

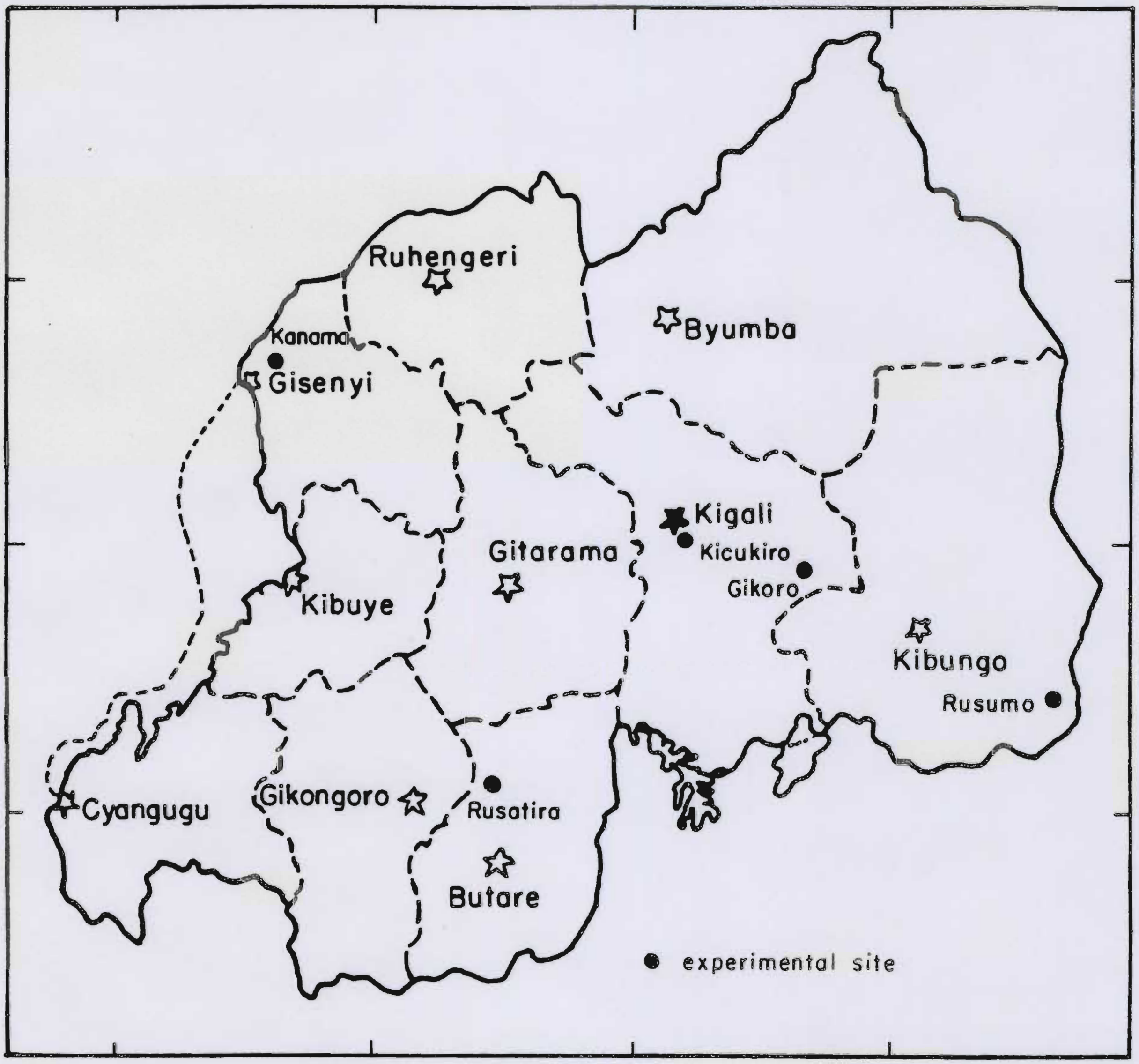


Figure 2.1. Republic of Rwanda: prefectural divisions and experimental sites.

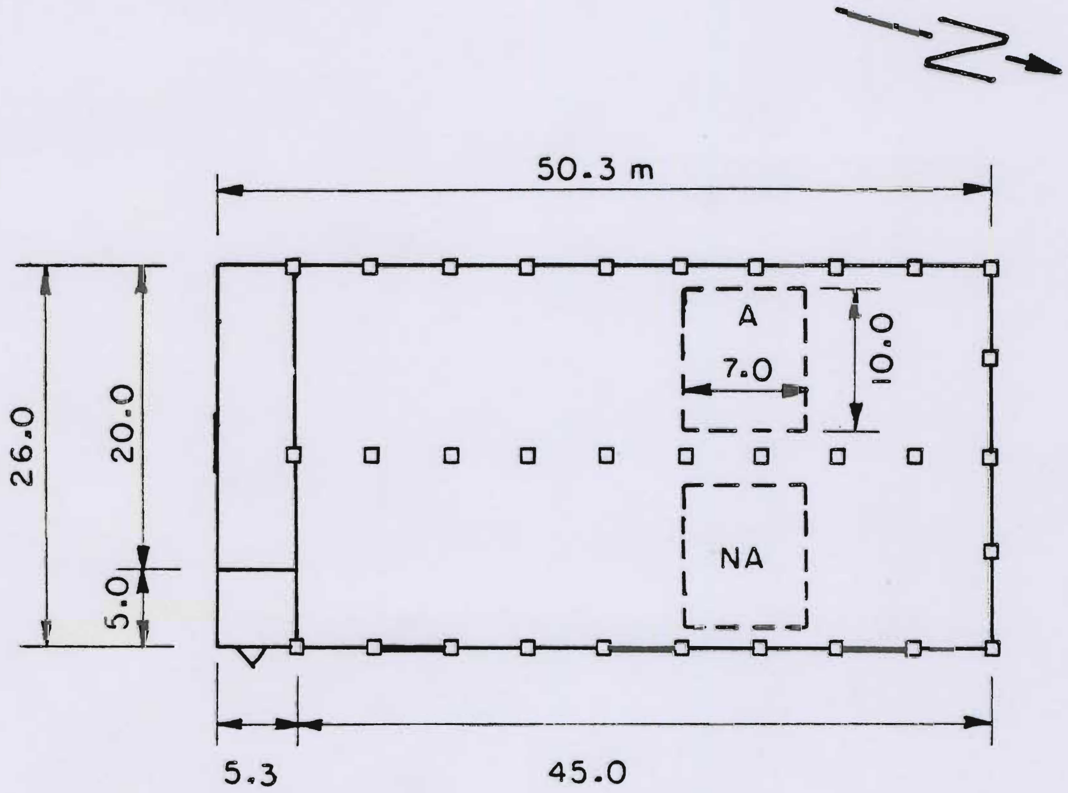


Figure 2.2. GRENARWA warehouse in KICUKIRO: general layout and location of two stacks used in the large pile aeration experiments (A = aerated pile, NA = non-aerated pile).

a way that there is a clearance of 0.40 m between the top of the walls and the roof. A large meshed screen covers this opening at the long side of the building, while translucent plastic sheeting is used at the two other sides. The roof itself has no ventilation openings. The long axis of the building is basically oriented in a north-south direction. At the east side three large metal sliding doors give access to the storage area. A loading platform or truck ramp in front of each gate facilitates the loading/unloading operations.

2.1.2. Handling

Beans and grain sorghum are brought to the warehouse in bags by merchants, cooperatives and farmers. The delivered quantity varies from a few kilograms to several tons. The larger quantities are brought in by trucks. No standardized quality evaluation is performed before accepting the products but a rudimentary inspection of the grain may take place at the gate. Grain that is judged to be of a 'very poor quality' (large numbers of live insects, extensive mold damage, too many large stones, ...) may be refused at this point. After weighing the delivered quantity, all bags are opened and dumped on the floor in a large pile. Actellic, a stored grain contact insecticidal dust, is then mixed in manually at a rate of 0.1% by weight. After that the grain is rebagged to a standard weight per bag and the bags are closed by hand sewing. Both jute and plastic woven bags are used, depending on their availability. However, the two bag types have not usually been used together in a given pile. Jute bags are filled with 90 kg of grain, while plastic bags can hold 100 kg. When enough bags are ready, the construction of a stack is started.

The first layer of bags is placed on wooden pallets (2.00 x 1.00 x 0.05 m) made of Eucalyptus wood. The size of a single pile depends on the warehouse layout and dimensions. In the Kicukiro warehouse a large stack usually covers about a 10.0 x 10.0 m area and has a height of around 5.0 m, which corresponds to 22 layers of bags. A bag conveyor is used to facilitate the construction of the stacks whenever it is in operating condition. Otherwise all work is done manually.

After the stacks are in place they are fumigated with phosphine gas (Phostoxin). This is done by placing Phostoxin tablets on the sides of the stack up to a height of about 2.0 m. After that the stacks are entirely covered with large plastic tarps to prevent the gas from escaping. The tarps are held down to the ground by placing sand 'snakes', wooden pallets or beams on top of them. During fumigations the warehouses are locked for three or four days. Following that they are ventilated for one day before laborers are allowed back in. Further technical management is limited to additional fumigations whenever large numbers of live insects are observed on the outside of several piles.

Storage periods for beans and sorghum in warehouses vary from a couple of months to about a year.

2.1.3. Problems Encountered

The main problems encountered when storing beans for a longer period of time are the gradual loss of cookability and flavor, the changes in color of the seed coat and the damage done by insects and fungi. All three types of quality deterioration are enhanced by high temperature and high relative humidity conditions.

The loss of cookability, i.e. the failure to soften during cooking is caused by slow, irreversible enzymatic changes occurring in the bean cotyledons (Aquilera and Stanley, 1985). This 'hard-to-cook' defect becomes more pronounced after several months of storage and is therefore found mainly at the government and the cooperative storage levels. It also interferes with the government's plans to store a strategic reserve of beans on a long term basis (possibly up to three years) to distribute during periods of famine. In addition, before becoming uncookable, hard beans require considerably more time and energy to soften, which is a serious problem in a country like Rwanda where wood fuel is increasingly scarce and expensive.

The naturally vivid colors of the seed coat fade rapidly with the aging of the beans. Consumers associate the loss of color brightness with a hard and less palatable product, requiring prolonged cooking times. Thus, the change in color is a strong indicator of consumer acceptability of beans.

The main pests causing losses at all levels of storage in Rwanda are insects, molds and rodents. The predominant insect pests of stored beans are two bruchid species: the bean weevil (Acanthoscelides obtectus) and the Mexican bean weevil Zabrotes subfasciatus). The larvae of both cause damage by boring holes within the cotyledons as they develop and prior to emergence of the adult stage. A.obtectus can infest bean pods in the field prior to harvest. The major insect pests of stored sorghum in Rwanda are the rice weevil (Sitophilus oryzae) and secondarily the lesser grain borer (Rhyzopertha dominica). A number of other species are found less frequently including two moths, Plodia interpunctella and Sitotroga cerealella. Under favorable conditions, successive generations of these insects can lead to the build-up of substantial populations and significant grain loss.

The range of conditions for development and reproduction of these insects varies according to species. The minimum temperatures required for A.obtectus and Z.subfasciatus are 17^{O} and 20^{O}C, respectively. As a result, A.otectus is found throughout most of Rwanda, but Zabrotes is a problem only in the lower altitudes where higher temperatures prevail (eg: Bugesera and Gisuku). The optimum temperature range for both is the high 20s -

low 30s. The maximum is about 35°C. The minimum temperatures required for development of S.oryzae and R.dominica are 17° and 23°C, respectively. Their optimum ranges also vary: high 20s for the former, low to mid 30s for the latter. The maximum is a few degrees more than the optimum range. Thus temperature presents itself as a potential mechanism for insect control, either by creating and maintaining low temperatures (<17°C) or even high temperatures (>35°C).

The other important environmental factor is relative humidity (RH) within the grain mass, especially as it is influenced by grain moisture content. The optimum range for the bruchids is 50 to 75% RH (11 to 16% moisture content in beans, 12 to 15% moisture content in sorghum). S.oryzae requires an RH above 60% but R.dominica is somewhat tolerant of lower RH. Contrary to temperature, RH seems to offer little opportunity for insect control.

The other major group of organisms causing damage to stored grain are fungi. Storage fungi (primarily species of Aspergillus and Penicillium) can grow within a wide range of temperatures (0-70°C with an optimum of 35-40°C), though development is reduced at lower temperatures. Active growth of certain species can raise temperatures and cause 'hot spots.' The most practical way to control fungi is to reduce and maintain grain moisture contents below an equilibrium relative humidity of 65-70%. This is equivalent to moisture contents of 13.5 to 14.5% and 13.5 to 14%, respectively for beans and sorghum.

Reduced oxygen and increased carbon dioxide levels, such as occur in sealed hermetic storages, can also limit development of insects and fungi. Favorable combinations of all these environmental factors provide more effective control than a single one alone.

The main rodent pests of stored grain in Rwanda are thought to be the roof rat (Rattus rattus) and the house mouse (Mus musculus). Precise loss estimates are not available in Rwanda and are difficult to obtain, but rodents have been reported as a problem at all storage levels. Besides actual consumption of food products including grain, rodents contaminate considerably more with urine and droppings, cause damage to packaging and structures, and are vectors of certain human diseases. The four main control methods are: rodent-proofing and sanitation, fumigation, poison baiting, and trapping. From a practical standpoint, rodents are not susceptible to control by manipulating temperature, relative humidity or grain moisture content. OPROVIA warehouses are partially rodent-proofed, but large kills are made when fumigating with Phostoxin to control insects.

Obvious problems in the grain handling system are the large amount of warehouse space taken up by the receiving activities and the long periods of time trucks spend waiting in line to unload. The time spent waiting in line was particularly severe in 1986 when government policies dictated purchasing directly from producers with 30 kg lots or less. Other problems include spillage resulting from hand sewing of bags and the lengthy process involved in treating beans and sorghum with insecticide before rebagging. Also, capability exists for improving product quality by screening to remove foreign material (Thompson, 1985).

2.2. Cooperative Level

2.2.1. Structures

In Rwanda two basic types of storage structures are used at the cooperative level: silos and hangars. More than 100 units have been built throughout the country during the last 10-15 years with the financial support of Catholic Relief Service (CRS), USAID and other donor organizations. In the earlier stages silos were much preferred. They were all built following construction plans developed by Kansas State University and CRS (Burke and Pfost, 1976). The plans have never been modified since. Silos are still the predominant type, but lately hangars have received more attention, mainly because this type of structure lends itself better to uses other than long-term storage (meeting hall, short-term storage of coffee, etc.) which makes them an attractive alternative in small rural communities. The average storage periods are six months for beans and one year for sorghum. However, storage periods for beans of up to one year are no exception. Most cooperatives are directed by an elected board which is in charge of the overall management of the cooperative. The board hires and supervises the storage manager who is responsible for the daily operations.

A cooperative silo typically consists of a rectangular rock and/or brick building subdivided in six individual cubical compartments (2.5 x 2.5 x 2.5 m). The entire building rests on a reinforced concrete slab which is suppported by rock foundations under the silo and compartment walls. Only these foundations rest on an underlying rock bed so that the remainder of the building floor is not in direct contact with the soil. A layer of plastic sheeting is placed in the concrete floor to prevent moisture migration from the ground into the silo. The walls are made of kiln-dried clay bricks reinforced with 8 mm diameter reinforcing rods placed horizontally in cement mortar every 3 to 4 courses throughout interior and exterior walls. The walls are plastered with cement on both inside and outside surfaces. The ceiling consists of narrow reinforced concrete slabs placed side by side. The spaces between the slabs are sealed with cement. The inside compartment walls are covered with a smooth layer of cement plaster.

Each compartment has a storage capacity of 12 to 15 tons and can only be accessed through a rectangular man hole located near a corner in the ceiling. The man hole is covered with a hinged metal door that can be bolted to the ceiling. The entire building is covered with a metal gable roof. This roof is constructed high enough for people to work under in an upright position. A ladder or a ramp provides access to the space above the compartments. A horizontal emptying spout is installed through one of the outside walls at floor level near one of the corners of each compartment. It consists of a round steel pipe 12.5 cm in diameter and a threaded plug. When a compartment is filled, the man hole and emptying spout are locked with padlocks for security reasons. Usually a small shop and office for the manager are constructed under the same roof. Rain water falling off the roof and run-off water from neighboring fields are collected and evacuated through a system of cement gutters installed around the entire silo at a distance of 0.80 m from the walls.

These silos were originally designed to provide airtight storage conditions. In this type of storage the respiration of the grain, insects and molds lowers the oxygen level and raises the carbon dioxide level of the air within the storage space to such levels that insects can no longer survive. In practice it is very difficult to obtain airtight conditions. Opening such a silo rapidly restores the oxygen and carbon dioxide supplies to near their original levels. Therefore, this technique is only suitable for long-term storage. It takes only a small leak to undo the effects of airtight storage. The silos in Rwanda have weathered considerably over the years. Cracks have developed in the ceilings, especially around the man hole. Also the emptying spouts are often not sealed 'airtight. Therefore, they should no longer be considered as airtight structures. In fact, it is questionable whether structures of this design, even when new, are capable of achieving truly airtight storage conditions.

Hangars are rectangular (12.0 x 6.0 m) brick buildings designed for bag storage. They have about the same storage capacity as the silos. The walls rest on a reinforced concrete slab, that is supported by rock foundations under the walls and by a sand layer elsewhere. The foundations and the sand rest on a rock bed. A layer of plastic sheeting is placed between the concrete and the foundations/sand to prevent moisture migration through the floor. The walls are about 2.5 m high and carry a concrete ring beam that supports a saddle roof. The walls have several 0.20 x 0.80 m ventilation openings at 0.40 and 2.20 m from the floor. The roof consists of sheet metal panels. Since the walls are windowless, some of the metal panels have been replaced with translucent ones for lighting. Also, a small shop and office for the coop manager are attached to the storage building.

2.2.2. Handling

Filling and emptying a silo are essentially manual operations. After receiving and bagging the grain the bags are hoisted on top of the silo with a single pulley and manpower, and beans or grain are poured into the compartments through the man hole. At this time a contact insecticide such as Malathion or Actellic may be applied by alternating layers of grain and insecticide. Once the silo is filled, it is fumigated with Phostoxin to control the development of insects. Usually it remains closed until the time the grain is sold again. Monitoring of the quality of the stocks during storage is nonexistent. Grain is removed from a compartment by raking it out through the emptying spout with a small t-shaped device specially made for this purpose. Given the length of the emptying spout and its horizontal position the silo cannot be emptied by gravity. Although this does not seem to be an efficient way of handling the grain, it provides an added security in case someone would try to steal some grain and leaves the spout open.

At the hangars grain is received, mixed with contact insecticides (Malathion and Actellic) and bagged. The bags are then stored in piles placed on wooden pallets. Once this operation is completed, it may be followed by a fumigation treatment.

2.2.3. Problems Encountered

The results of the storage survey (Dunkel et al., 1986) and other observations showed that insects and molds are the major causes of storage losses at the cooperative level. In hangars rodents pose an additional problem. Preliminary measurements have shown that large temperature increases occur as a result of biological activities. It is well known that molds develop best in a high moisture environment and that insect populations increase very rapidly under favorable temperature conditions. However, no detailed information is available on the average microclimate that exists within these silo compartments, nor how this might change over time and at different locations within a compartment. Anticipating that in certain instances large temperature gradients might occur, it was judged useful to attempt to keep temperatures uniform and at low levels.

It was also observed that the managers of cooperatives do not closely monitor their stocks and therefore are in no position to reduce their losses by taking corrective actions as soon as a potential problem is detected. Sometimes silos and hangars remain closed for as long as 6 months. The results can be catastrophic when a small problem has time to develop. A high turnover rate of silo managers has resulted in a situation where most of them lack a basic understanding of the technical aspects of grain storage. It should be mentioned, however, that a thorough inspection of a silo is difficult to accomplish because of the low accessibility of the individual compartments. Also none of them has the basic equipment (probe, thermometer, sieve, ...) to perform a regular inspection. Most managers are willing to discuss the previous losses they may have experienced. However, it is very difficult to get a clear idea of the spoilage patterns of the quantities lost. This is mainly due to the fact that by the time the spoiled grain reaches the emptying spout most of the pattern is already disrupted. Therefore, most first hand information is sketchy at best.

Many cooperatives are experiencing financial hardships trying to keep the costs to their membership to a minimum. Most of the cooperatives lack the funds to fill their storage structures to capacity at least once a year. Marketing advisors have suggested that a more frequent turnover of stocks combined with contracts with large institutional buyers is one way of increasing profits and improving their financial situation. This requires, however, that the loading and unloading of the silos be faster.

Cash flow problems are so severe that some hangars cannot afford to procure bags and pallets. As a result, grain is sometimes stored in bulk on the floor and against the walls. In such cases the stock becomes quite vulnerable to moisture migration through the floor and walls. It also renders fumigation a hazardous undertaking.

Finally, the widespread incorrect use of insecticides and fumigants at the cooperative level poses a serious problem. In most cases the dosages are insufficient and/or applied incorrectly. In many instances this is related to a basic lack of information and resources. This not only results in ineffective treatments (while giving the managers a nice though false feeling of security!) but also increases the danger of developing resistant insect populations. Insect resistance to Malathion has already been identified in Rwanda and neighboring countries. In practice this leaves the country dependent on only two products (Actellic and Phostoxin) to protect stored grain and alternatives do not seem to be immediately available. Thus, better use of existing methods should receive a high priority.

2.3. Producer Level

2.3.1. Structures

Most of the beans and sorghum produced in Rwanda are stored and consumed on the farm. It is estimated that only 30% of these crops are marketed. Thus the effectiveness of storage methods at the producer level is important to Rwanda's overall production and food supply.

Baskets are the predominant on-farm container for storing beans and sorghum and accounted for two-thirds of those observed in a recent survey (Dunkel et al., 1986). There are two basic types of baskets in use: a taller, narrower type and a shorter, wider type. Both are locally made, woven reed structures which are usually uncovered and lined with a mixture of cowdung and mud. To a lesser degree, these crops are also stored in clay pots, metal oil drums, and sacks (primarily jute). The use of exterior granaries has declined considerably. They are still used in some regions (northern and southeastern Rwanda) for storing unthreshed heads of sorghum. Gourds (large, hollow dried fruit of the calabash plant) and the 'imboho' (traditional transporation and storage receptacle made from dried banana sheaths) are both occasionally used for storing beans.

With the exception of the granary, these containers are located within farm houses. Thus grain is stored in one structure which is surrounded by another, larger structure. Consequently, building materials of the house as well as placement of the container within the house are important factors because they influence the storage microenvironment. Nearly 50% of the houses surveyed by Dunkel et al. (1986) had metal roofs; the others were made from either clay tiles or straw thatch. Most of the houses did not have ceilings which could provide some tempering effect or thermal protection, especially where metal roofs occur. The majority of walls and floors were of dried mud.

In most cases, the containers were placed in a separate room designated for storage. However, they were also found in sleeping areas and foyers. In all three situations, the containers were sometimes near the cooking area which may affect grain moisture content (drier air) and insect control (smoke and even heat). Most containers were elevated off the floor, usually on large stones, which minimizes moisture uptake from the floor and allows passive aeration around and through the container bottom.

2.3.2. Handling

Bean seeds in pods and sorghum grain in panicles (heads) are left by farmers to dry on the plant in the field for several weeks following physiological maturity. The length of this initial dry-down period is seasonably quite variable and depends on weather conditions (rainfall, humidity, dew). Bean plants are then pulled and carried to the homestead ('rugo') where they are piled loosely on the ground for further drying. When beans are considered sufficiently dry, they are removed from the pods by beating the plants with wooden sticks. The threshed beans are gathered off the ground and then winnowed using a round, relatively flat, woven reed basket to remove dirt and other fine foreign material. At the same time, farmers often hand-pick out larger and heavier foreign material such as stones and chaff, and even severely damaged beans. In similar fashion, sorghum heads are dried on the ground at the homestead. Grain is then threshed with sticks and cleaned by winnowing if the crop is to be stored as grain.

The threshed, rough-cleaned grain is then ready to be placed in storage. Prior to storage, grain may be treated against insects. A recent survey found that three-quarters of the farms treated their beans (Dunkel et al., 1986). One half of those who treated used synthetic contact insecticides (e.g. Malathion, Actellic); the rest employed ashes (often from banana leaves), kaolin (fine clay material), and to a lesser extent, lateritic soil, chili peppers ('pilipili') and various local plants. Fewer farmers (roughly half) treated their sorghum stocks.

Grain is gradually withdrawn from storage over time. Small amounts of beans are generally removed every few days to be cooked as the primary staple food for the family. Sorghum, mainly used on the farm for sprouting to provide malt for beer making, is also withdrawn on a regular though less frequent basis. Sorghum is used in a porridge form, too. This kind of utilization pattern influences the storage method used and the magnitude of losses incurred.

Since most farmers grow two bean crops a year, storage usually does not exceed six months. A survey indicated that bean stocks (January 1985 crop) were entirely depleted within four months following harvest (Dunkel et al., 1986). Since only one crop of sorghum is produced each year, though at different times depending on the region, the storage period tends to be longer and may attain 12 months. Again, because of gradual use, the amount of sorghum still in storage at the end of this period is relatively small.

2.3.3. Problems Encountered

A survey of approximately 50 farms throughout Rwanda in 1984-85 found that weight losses during storage were less than 5% for beans and only 2% for sorghum (Dunkel et al., 1986). Bean losses were greater in the lower altitudes (e.g., Kibungo) where higher temperatures prevail and more rapid build-up of insects occurs. The principle factors contributing to these comparatively low levels of loss are:

- small quantities stored (100 kg on average for beans)
- short storage period (total of 3-4 months on average, but mean period shorter than this given utilization pattern)
- frequent withdrawals of small amounts of product which
    1) gradually reduces quantity in storage
    2) causes regular observation of grain quality and and storage conditions, which in turn allows early detection of storage problems.

Certain quality problems (losses other than weight) such as germinability, bean cookability and color change are not important because of good storage conditions and short storage periods. It should be emphasized, however, that these loss data are only averages, and obscure the fact that certain farmers do experience storage problems and need assistance.

High (unsafe) moisture content (mc) of grain is normally not a problem. Beans averaged 13-16% mc early in storage, with the June harvest somewhat drier than the January harvest (Dunkel et al., 1986). Sorghum was found to be less than 13% mc one month after the 1984 harvest (Dunkel et al., 1986) and about 11% on average 2-3 months after the 1986 harvest (FSM II Project, unpublished data). Thus adequate drying is possible at the farm level, and mold damage is minimal.

Insects are the most important cause of current losses and potentially even more significant with prolonged storage. Insect control is relatively effective though variable at present, and an obstacle to long-term storage. Rodent losses are difficult to determine with precision. Entire seeds are often eaten or removed. Rodents contaminate with feces and urine more grain than they consume. The producers in certain regions consider them a major problem. Traditional use of traps and cats seems only marginally effective; raticides are almost non-existent. Most traditional storage structures such as granaries and baskets are not effective barriers to either insects or rodents. Improved methods of managing insect and rodent pests coupled with more effective dissemination of information to more farmers will be increasingly necessary.

3. QUALITY EVALUATION

An important part of the long-term storage experiments consisted of monitoring the quality changes that occurred over time in a given stock. It was therefore necessary to have standardized procedures that allowed objective measurement of the parameters that were considered relevant to either the overall quality of a stock at the time of sampling or to its continued storability. Since both beans and sorghum are intended for either human consumption or planting purposes, it was also important to include factors that reflect the food and seed quality perceptions of the Rwandan consumer.

The careful sampling of stocks constitutes the first essential step in any evaluation procedure, for if a sample does not represent the stock it was drawn from, the whole process of sample analysis is rendered useless. In order to obtain truly representative samples, it is necessary to use equipment and techniques that are adapted to the circumstances. Samples of about one kg were sufficiently large to perform all routine laboratory tests. Large bulk storages such as the cooperative silos were sampled by inserting a deep bin cup probe several times and at different places in the layer to be sampled. Bagged grain was sampled by piercing the bag in 6-10 different places with a bag trier. Grain stored in small containers was either sampled with a standard grain probe or by hand.

Once samples were collected they were analyzed in the Grain Quality Laboratory located at the OPROVIA Administrative Headquarters in Kicukiro. This laboratory follows a series of standard procedures to determine the physical quality of beans and sorghum. The factors routinely evaluated are the test weight, moisture content, foreign material and numbers of live and dead insects. In the case of beans, these tests are followed by an in-depth damage evaluation and an instrumental hardness determination.

The physical quality evaluation begins with measuring the test weight of an unsieved sample using a Winchester apparatus (volume of 1101.2 cm^3). Next the moisture content is determined as the calculated mean value of three separate measurements taken with a Motomco moisture meter (model #919) on a 250 gram sample drawn from the test weight sample. The entire Winchester sample is then shaken 30 times over a sieve (0.32 x 1.91 cm oblong hole sieve for beans and a 0.3175 cm triangular hole sieve for sorghum) to collect, identify and count live and dead insects. All material falling through the sieve (except the insects) combined with the large non-grain material remaining on the top of the sieve is weighed to determine the foreign material. Approximately 200 grams of the sieved sample are then placed in a quart mason glass jar and incubated for about 10 weeks at room temperature (22-23°C). After this period these subsamples are sieved again to count the total number of adult insects having developed from the egg and larval stages. Incubation tests were not performed routinely in this research, but depended somewhat on the availability of laboratory equipment and the relative importance of the experiment.

After the physical evaluation of the sample is concluded, a grain damage analysis is performed on 300 beans randomly selected from the sieved sample. First the beans are divided into three groups of 100 beans. Each group is then subdivided into 11 damage categories: sound beans, insect damaged, visibly moldy, rodent damaged, germinated, broken or discolored beans, seeds with a torn pericarp, small, wrinkled or dented beans. A bean that shows different types of damage or defects is only accounted for in the category of its most serious defect. The number of beans in each category are then counted, and each category is averaged over the three groups. The results are therefore expressed as a percent by number and not by weight. To obtain actual damage percentages by weight, each category would have to be weighed or multiplied by a weight conversion factor. Table 3.1 was developed during work on the Quality Standards component of the project. It provides a conversion factor to relate quality data in percent by number to percent by weight. All analyses for experiments described in this document were carried out and are reported on a percent by number basis. Table 3.1 can be used for estimating those values on a percent by weight basis.

It should also be noted that some of these damage categories are not at all influenced by storage condition but are due to genetic factors or pre-harvest conditions. The categories that are considered typically - although not exclusively - storage related are the insect, mold and rodent damaged and the germinated beans. Changes observed in the sum of these four categories are considered a good indicator of losses incurred during storage.

Beans can also be damaged to different degrees, and beans with minor defects may still be acceptable to consumers for either consumption or planting purposes. Based on the results of a survey (Dunkel et al., 1986) organized by the laboratory staff among Rwandan women farmers, two more damage categories were defined and included in the damage reports: beans considered unfit for consumption ('inedible') or unfit for planting purposes ('unplantable'). These two categories probably best reflect how Rwandans judge the overall food and seed quality of a given sample. Unfortunately, it is not yet possible to mathematically derive these two categories from the other damage categories.

The instrumental hardness of a bean sample is determined with a Chatillon tester by measuring the mean peak force necessary to completely pierce 100 individual cooked beans with a circular, flat faced steel punch 3.175 mm in diameter. The beans are first cooked for three hours in boiling water (boiling temperature ca. 97°C) to which 1/2 teaspoon of NaCl salt has been added. Beans are considered 'hard-to-cook' when the maximum piercing force exceeds 4.40 Newton. The percentage hard-to-cook (% HTC) beans in the

Table 3.1. Proposed factors for converting quality data on Rwandan beans of various damage categories from percent by number to percent by weight.

Damage Category	Mean Seed Weight (g)	Weight ratio of damaged bean to sound bean (%)	Proposed conversion factor (%)
Sound (no damage)	0.41	100	100
Insect	0.29	71	70
Mold	0.31	76	75
Rodent	0.26	63	65
Germinated	0.36	88	90
Shrunken/shriveled	0.17	41	40
Broken	0.21	51	50

Examples:

- 10% broken bean damage by number converts to 5% damage by weight
- 10% sprout damage (germinated) by number converts to 9% damage by weight

sample is another indicator used to evaluate the hardening of a bean stock. After reviewing a large number of bean hardness data, Breene (1987) concluded that the % HTC beans provide the best indication of the development of a hardening problem. The mean peak force data are considered useful in confirming the % HTC data, especially in the early stages of the hardening process. For the bean mixtures produced in Rwanda, HTC values of approximately 30% represent a baseline level reached during the first few months after harvest. He also indicated that the high variability observed in some of the hardness data is probably due to variation in bean sizes and types within the mixtures. Trends observed are therefore often more important than the absolute values resulting from the tests.

4. OPROVIA/GRENARWA STORAGE LEVEL EXPERIMENTS

4.1. Introduction

Based on the present situation and the problems encountered as described in Chapter 2, it was decided to undertake the following activities:

- equip two large piles of bagged beans with temperature monitoring equipment to evaluate their thermal behavior
- install an aeration system in one of these piles to evaluate the effectiveness of such a system in lowering and equalizing the temperatures within the pile
- study the thermal characteristics of the warehouse at Kicukiro in order to predict the effect of insulation on the microclimate within the warehouse
- evaluate the effect of aeration on the development of insects
- study the differential resistance against insect penetration of jute bags and plastic woven bags
- evaluate ambient air drying and aeration in bulk storages
- analyze and discuss the construction plans of the warehouses.

4.2. Large Pile Temperature Monitoring and Aeration Experiment

4.2.1. Methodology

The site selected for this study was the GRENARWA warehouse in Kicukiro. This warehouse is normally used for the long-term storage of beans and grain sorghum. The temperatures and bean quality of two large stacks were monitored during a period of almost one year. Both piles were treated like any other pile handled by GRENARWA, except that one of the piles was equipped with a one-duct aeration system. Fig. 2.2 shows the location of the selected stacks within the warehouse. The beans were harvested during the month of January 1985 and purchased by GRENARWA from different individual merchants during February and March.

The one-duct aeration system is shown in Fig. 4.1. The walls of the duct were made with cement blocks placed end to end directly on the warehouse floor, without the use of mortar. The blocks were 0.40 m long, 0.20 m high and 0.15 m wide. Each duct wall contained 21 blocks and had a length of 8.40 m. The distance between the duct walls was 0.50 m, giving a cross sectional duct area of 0.10 m^2. The duct began at 1.50 m from, and ran perpendicularly to the warehouse wall. The duct was closed off at the end with two blocks and terminated at 1.60 m from the side of the pile. The first 1.50 m of the duct was covered with plywood to

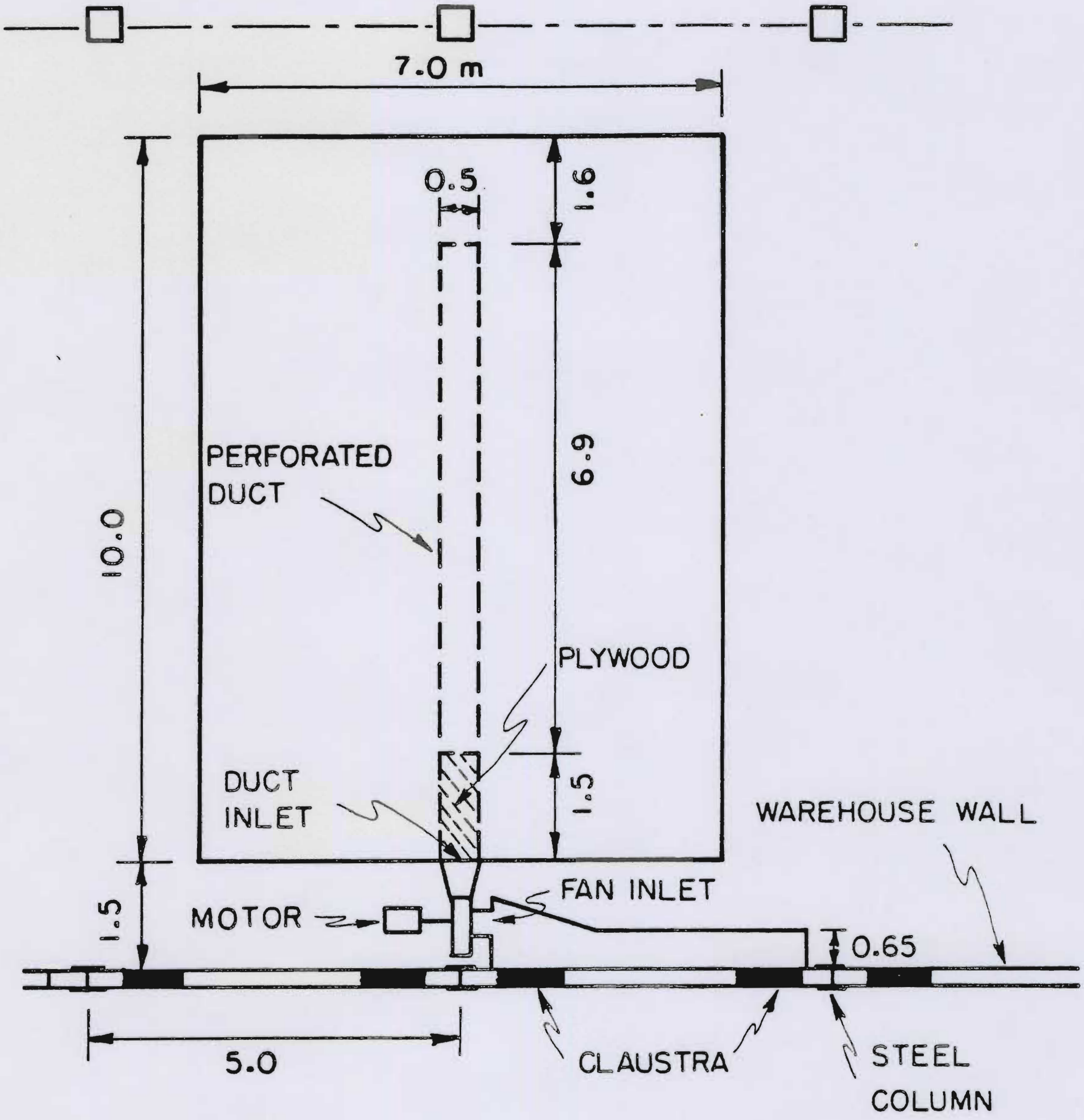


Figure 4.1. One-duct aeration system used in the large pile aeration experiment (KICUKIRO warehouse).

prevent the escape of air at that point. The remaining 6.90 m were covered with wooden pallets of the kind normally used by GRENARWA. The duct was constructed on February 11. The pile construction began at the same time and was completed on February 26.

After completion the pile contained 3,095 jute bags, each weighing 90 kg, or 278.55 MT of dry beans. During construction of the pile, five bags at the center of the stack (position C, see Fig. 4.2), located at layers 2, 8, 14, 20 and 22, were sampled and equipped with a type-T (copper-constantan) thermocouple at the center of each bag. An additional ten bags, five on one side (position A) and five on the side facing the center of the warehouse (position B) were sampled and instrumented after the pile was finished. Duct tape was used to make sure the thermocouples stayed in place. The sampled and instrumented bags were all tagged and labeled A1 through A5, B1 through B5, and C1 through C5.

On March 16, a fan (Dayton, model 3C073) was hooked up to the duct. The fan was connected with a variable speed belt to a single phase electric motor (1 1/2 HP, 220 V, 11.5A, 50 Hz). The inlet duct to the fan consisted of a plywood construction covering two claustra in the warehouse wall so that only outside air was used for aeration purposes. The fan delivered 1.70 m^3/sec at 1,800 RPM and a static pressure of 19 mm water column. During the first three months of the experiment, aeration was applied every night from midnight until 6:00 a.m. (except during fumigation treatments in the warehouse) since this was the coolest period of the day. After this period temperatures within the pile had stabilized and aeration was reduced to one or two nights a week, simply to maintain the temperatures.

The construction of the second pile started on March 12 and was completed on March 23. Unlike the aerated pile which consisted of jute bags, this pile was built with woven plastic bags. In total 20 layers of bags were put in place. It contained 2,178 bags of 100 kg or 217.8 MT. The pile dimensions were 7.0 x 10.0 x 4.5 m. A disadvantage of the woven plastic bags is that they slide more easily than jute bags, especially when they are filled to their rated capacity. Four layers (2, 7, 14 and 20) were sampled and instrumented with thermocouples at five different locations (Fig. 4.2). These five locations are the center of the pile (C), two sides (A and E) and two quarter points (B and D), i.e.,. points halfway between the center and the sides. The monitored bags were tagged and labeled A11 through A14, ..., E11 through E14.

On May 25 all the bean piles in the warehouse were fumigated. This was done by placing Phostoxin tablets between the bags at the outside of the piles and covering the piles for three days with gas impermeable tarps. The liberated gases corroded the exposed copper parts of a large number of thermocouple wires in the aerated pile, so it was decided to take that pile down to replace the damaged wires and to sample the tagged bags. At the same time bags at the quarter points and in layer 21 were sampled,

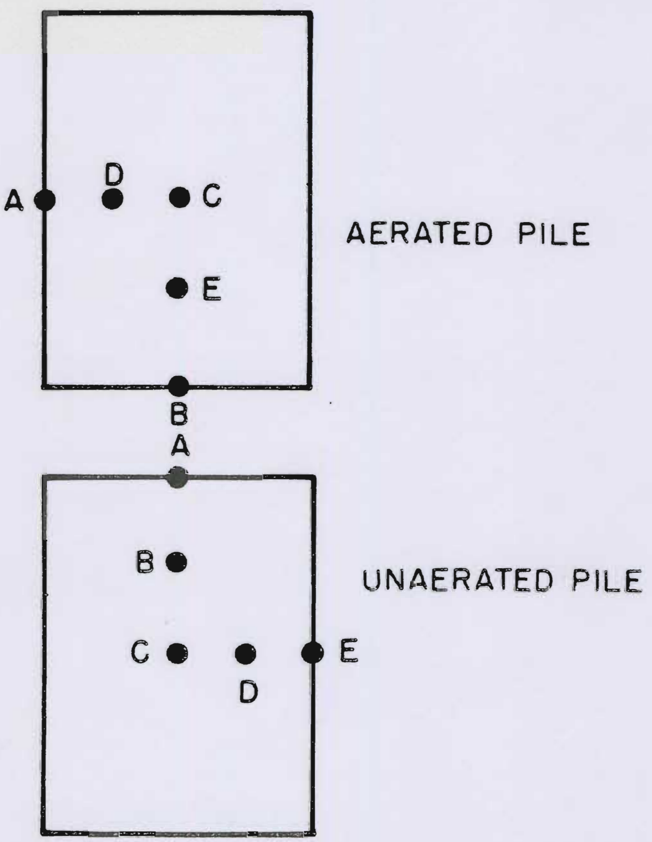


Figure 4.2. Thermocouple positions within the aerated and the non-aerated piles.

tagged and instrumented. This operation started on June 4 and was completed on June 10.

Initially temperatures in both piles were measured on an almost daily basis. Later a weekly schedule was maintained. The ambient temperature and the relative humidity in the warehouse were measured in between the two monitored stacks (at 1.0 m above floor level) and on top of the aerated pile with Cole-Parmer hygrothermographs (model 8379, 7 day chart rotation).

4.2.2. Results and Discussion

The average temperature data and the results of the quality analysis for the aerated pile are given in Tables 4.1-4.5 and for the non-aerated pile in Tables 4.6-4.10. These tables show the individual results for each of the sampling points as well as the average values per location, per layer and for the entire pile. The ten-day mean minimum and maximum temperatures recorded inside (in between and on top of the stacks) and outside the warehouse are shown in Fig. 4.3. The ten-day mean maximum and minimum relative humidities in between and on top of the stacks are shown in Fig. 4.4.

The actual amount of data collected during this experiment is inherently limited because of the nature of the experiment. Sampling large piles is impossible without taking them down and rebuilding them, which takes considerable time and necessarily changes the storage environment. Only factors that can be measured remotely, such as temperature, are well documented. Those that require obtaining a physical sample are necessarily limited to an observation at the beginning and the end of the storage period. It should also be emphasized that it was not feasible to control the storage environment in any way. The results of this and other experiments are only a number of pieces of a large jigsaw puzzle and therefore have to be combined with findings obtained in other project components. Finally, the sheer number of samples passed on to the laboratory by this and other components made it impossible to analyze all of them in a timely fashion, and priorities had to be set for reducing the number of samples. This explains the limited number of results available for the beginning of the experiment.

The temperatures shown in Table 4.1 are average values taken over the entire storage period, except those mentioned for positions D and E, and for layer 6, which are average values calculated over the period between 3.5 and 11.0 months of storage. The average temperature in the aerated pile (AP) is 2.1°C lower than in the non-aerated pile (NAP).

The temperatures in Table 4.6 show the presence of temperature gradients with decreasing values from the center to the outside in the undisturbed pile. The lateral gradients are more important than the vertical ones. The AP (Table 4.1) shows a modified temperature distribution with the lowest temperatures

Table 4.1. Average storage temperature and changes observed in some physical quality characteristics (moisture content, test weight and foreign material) of beans (Phaseolus vulgaris) stored during 11.0 months in an aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 6 layers (1,...6,5) of the pile.

(I = initial value, II = after 3.5 months, III = after 11 months)

Loc.	Temp. (°C)	Moisture Content (%)			Test Weight (kg/m^3)			Foreign Material (%)		
		I	II	III	I	II	III	I	II	III
A1	19.5	14.7	14.3	--	724.8	727.7	---	0.31	0.31	--
A2	19.7	14.8	15.1	15.0	741.5	735.0	753.3	0.58	0.62	0.69
A3	20.8	16.0	14.7	13.9	728.6	733.6	746.0	0.51	0.76	0.71
A4	21.8	16.2	15.4	14.8	739.6	735.7	748.9	1.46	0.99	1.43
A6	23.4	--	15.4	14.1	--	741.8	741.2	--	0.78	0.50
A5	22.1	14.6	13.6	12.9	724.8	733.6	735.2	0.31	0.71	--
B1	19.9	15.2	14.4	--	725.5	732.5	---	0.70	0.43	--
B2	19.8	15.3	14.3	15.2	729.5	731.3	741.5	0.59	0.47	0.44
B3	20.4	16.1	15.2	14.0	726.9	725.9	742.4	0.55	0.76	0.38
B4	21.4	16.2	14.1	14.6	739.5	736.5	700.5	0.79	0.78	0.62
B6	22.0	--	14.4	14.6	---	751.1	756.2	--	0.27	0.44
B5	21.3	14.9	13.2	14.1	729.0	733.7	737.9	0.72	0.74	0.70
C1	18.7	16.1	17.3	15.9	740.7	736.5	739.5	1.22	0.47	0.92
C2	19.0	15.6	15.4	15.7	725.5	719.4	745.7	2.39	0.45	1.32
C3	19.8	15.4	14.7	14.6	733.7	734.7	743.5	0.36	0.58	0.66
C4	21.4	15.0	14.5	14.7	729.3	735.7	742.1	0.59	0.47	0.62
C6	23.3	--	14.3	14.3	---	742.3	734.0	--	0.42	0.77
C5	21.9	15.5	13.0	13.1	738.6	745.7	754.7	3.04	2.41	4.31
D1	18.8	--	17.7	15.7	---	734.8	736.1	--	0.36	0.67
D2	19.1	--	14.7	15.6	---	740.2	757.8	--	0.53	0.53
D3	20.2	--	15.0	14.9	---	733.8	761.2	--	0.41	0.21
D4	22.0	--	15.4	14.8	---	730.8	739.4	--	1.04	0.69
D6	23.5	--	16.1	14.7	---	727.0	737.8	--	0.95	0.84
D5	22.1	--	15.1	14.6		745.1	742.0		1.57	1.24
E1	18.9	--	16.7	15.7	---	726.6	730.2	--	0.62	0.88
E2	19.2	--	15.5	15.2	---	733.4	737.6	--	0.27	0.32
E3	19.9	--	14.9	15.1	---	738.3	725.1	--	1.01	0.71
E4	21.6	--	15.7	15.2	---	726.9	737.7	--	0.65	1.00
E6	23.0	--	15.4	14.3	---	741.3	748.5	--	1.11	1.55
E5	21.9	--	13.0	13.9	---	732.3	738.7		0.53	0.82
Mean										
A	21.2	15.3	14.8	14.1	731.9	734.6	744.9	0.63	0.70	0.83
B	20.8	15.5	14.3	14.5	730.1	735.2	735.7	0.67	0.58	0.52
C	20.7	15.5	14.9	14.7	733.6	735.7	743.3	1.52	0.80	1.43
D	20.9	--	15.7	15.1	---	735.3	745.7	--	0.81	0.70
E	20.7	--	15.2	14.9	---	733.1	736.3	--	0.70	0.88
1	19.2	15.3	16.1	15.8	730.3	731.6	735.3	0.74	0.44	0.82
2	19.3	15.2	15.0	15.3	732.2	731.9	747.2	1.19	0.47	0.66
3	20.2	15.8	14.9	14.5	729.7	733.3	743.6	0.47	0.70	0.53
4	21.6	15.8	15.0	14.8	736.1	733.1	733.7	0.95	0.79	0.87
6	23.0	--	15.1	14.4	---	740.7	743.5	--	0.71	0.82
5	21.8	15.0	13.6	13.7	730.8	738.1	741.7	1.36	1.19	1.77
Total Mean	20.9	15.4	15.0	14.7	731.8	734.8	741.2	0.94	0.72	0.89

Table 4.2. Changes observed in the total number of insects, number of live insects, mean hardness and percent hard-to-cook grains of beans (Phaseolus vulgaris) stored during 11.0 months in an aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...E) and 6 layers (1,...,6,5) of the pile.

(I = initial value, II = after 3.5 months, III = after 11.0 months)

Loc.	Tot. # Insects/kg			# Live Insects/kg			Mean Hardness (Newton)			% Hard-to-cook		
	I	II	III	I	II	III	I	II	III	I	II	III
A1	18.8	7.5	--	0.0	0.0	--	2.34	2.83	--	12.0	6.0	--
A2	20.8	28.4	9.6	0.0	0.0	0.0	--	--	3.96	--	--	39.0
A3	34.9	45.8	4.9	0.0	0.0	0.0	3.20	3.42	4.35	17.0	18.0	49.0
A4	9.8	8.6	27.9	3.7	0.0	0.0	--	--	3.45	--	--	30.0
A6	--	20.8	84.5	--	0.0	0.0	--	--	4.48	--	--	53.0
A5	10.0	45.8	76.6	0.0	0.0	0.0	2.44	2.79	4.54	4.0	10.0	53.0
B1	23.8	23.6	--	6.3	0.0	--	--	--	--	--	--	38.0
B2	72.2	33.5	77.2	0.0	0.0	0.0	--	--	3.79	--	--	28.0
B3	56.2	7.5	25.7	6.2	0.0	0.0	--	--	4.20	--	--	42.0
B4	50.3	4.9	1.3	6.1	0.0	0.0	--	--	3.81	--	--	32.0
B6	--	0.0	2.4	--	0.0	0.0	--	--	4.11	--	--	42.0
B5	28.6	2.5	96.0	5.0	0.0	0.0	--	--	3.57	--	--	30.0
C1	8.6	9.9	6.1	0.0	0.0	0.0	3.16	3.47	3.81	22.0	26.0	33.0
C2	23.8	3.8	31.7	1.3	0.0	0.0	3.13	3.62	4.89	20.0	28.0	64.0
C3	16.1	11.1	56.2	1.2	0.0	0.0	2.72	2.95	3.89	12.0	14.0	37.0
C4	6.2	3.7	75.9	2.5	0.0	0.0	--	--	3.13	--	--	25.0
C6	--	3.7	7.4	--	0.0	0.0	--	--	4.38	--	--	50.0
C5	0.0	0.0	0.0	0.0	0.0	0.0	2.96	3.20	3.52	14.0	20.0	33.0
D1	--	1.2	16.0	--	0.0	0.0	--	--	4.18	--	--	41.0
D2	--	3.7	33.6	--	0.0	0.0	--	--	4.25	--	--	43.0
D3	--	9.9	17.9	--	0.0	0.0	--	--	3.35	--	--	24.0
D4	--	22.4	59.0	--	0.0	0.0	--	--	3.30	--	--	20.0
D6	--	25.0	8.6	--	0.0	0.0	--	--	4.33	--	--	55.0
D5	--	51.2	72.2	--	0.0	0.0	--	--	4.54	--	--	49.0
E1	--	42.5	52.2	--	0.0	0.0	--	--	4.89	--	--	64.0
E2	--	11.1	12.3	--	0.0	0.0	--	--	3.27	--	--	20.0
E3	--	27.1	60.1	--	0.0	0.0	--	--	3.50	--	--	31.0
E4	--	2.5	16.0	--	0.0	0.0	--	--	3.91	--	--	34.0
E6	--	18.4	41.3	--	0.0	0.0	--	--	3.21	--	--	61.0
E5	--	7.4	38.1	--	0.0	0.0	--	--	4.82	--	--	21.0
Mean												
A	18.9	26.2	40.7	0.7	0.0	0.0	2.66	3.01	4.16	11.0	11.3	44.8
B	46.2	12.0	40.5	4.7	0.0	0.0	--	--	3.90	--	--	35.3
C	10.9	5.4	29.6	1.0	0.0	0.0	2.99	3.31	3.94	17.0	22.0	40.3
D	--	18.9	34.6	--	0.0	0.0	--	--	3.99	--	--	38.7
E	--	18.2	36.7	--	0.0	0.0	--	--	3.93	--	--	38.5
1	17.1	16.9	24.8	2.1	0.0	0.0	2.75	3.15	4.29	17.0	16.0	44.0
2	38.9	16.1	32.9	0.4	0.0	0.0	3.13	3.62	4.03	20.0	28.0	38.8
3	35.7	20.3	33.0	2.5	0.0	0.0	2.96	3.19	3.86	14.5	16.0	36.6
4	22.1	8.4	36.0	4.1	0.0	0.0	--	--	3.52	--	--	28.2
6	--	13.6	28.8	--	0.0	0.0	--	--	4.10	--	--	52.2
5	12.9	21.4	56.6	1.7	0.0	0.0	2.70	3.00	4.20	9.0	15.0	37.2
Total Mean	25.3	16.1	36.1	2.2	0.0	0.0	2.85	3.18	3.98	14.4	17.4	39.3

Table 4.3. Changes observed in the percent beans damaged by insects, molds or rodents, and germinated or broken beans (<u>Phaseolus vulgaris</u>) stored during 11.0 months in an aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 6 layers (1,...6,5) of the pile.

(I = initial value, II = after 3.5 months, III = after 11 months)

	Insects (%)			Molds (%)			Rodents (%)			Germinated (%)			Broken (%)		
Loc.	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
A1	-	3.3	5.7	-	0.7	0.3	-	0.3	0.3	-	0.7	2.3	-	1.0	0.3
A2	-	0.7	1.7	-	1.0	1.0	-	0.3	0.0	-	0.0	0.3	-	0.0	0.7
A3	7.3	4.7	2.0	2.7	1.0	1.0	0.3	0.0	0.7	0.0	0.3	0.7	0.7	0.7	0.0
A4	3.0	5.0	1.3	2.3	0.7	3.0	0.3	0.3	1.0	0.0	0.0	0.3	1.0	0.0	1.3
A6	-	0.0	5.0	-	0.0	0.7	-	0.7	0.0	-	0.3	0.7	-	0.0	0.3
A5	4.0	6.3	5.7	0.3	0.3	1.7	0.3	0.0	0.7	0.3	0.0	0.3	0.7	0.3	0.7
B1	1.7	3.7	7.0	0.3	1.0	2.0	0.3	0.0	0.3	0.7	0.0	0.3	1.0	0.3	0.3
B2	4.7	3.7	2.3	1.3	1.3	3.0	0.3	0.0	0.0	0.0	0.7	0.0	0.7	0.7	0.3
B3	3.3	4.3	2.3	2.0	0.7	3.0	0.0	0.0	0.0	0.3	0.7	1.3	0.3	1.0	1.0
B4	1.3	1.0	3.0	2.7	1.3	1.3	0.3	0.3	1.0	0.3	1.3	0.0	0.7	0.7	0.0
B6	-	2.3	-	-	1.0	-	-	0.0	-	-	0.3	-	-	0.0	-
B5	-	7.7	-	-	0.0	-	-	0.0	-	-	0.0	-	-	1.0	-
C1	-	3.0	4.7	-	0.3	4.3	-	0.0	0.0	-	0.0	0.0	-	0.3	0.0
C2	-	1.3	0.7	-	0.3	2.3	-	0.3	0.3	-	0.3	0.3	-	1.0	0.0
C3	-	1.3	2.0	-	2.0	0.0	-	0.0	0.7	-	0.0	0.3	-	0.3	0.7
C4	-	1.0	5.0	-	0.3	3.3	-	0.0	0.0	-	0.7	0.7	-	0.3	0.0
C6	-	0.0	0.7	-	2.0	3.3	-	0.0	0.0	-	1.3	0.7	-	0.3	0.3
C5	-	1.3	2.0	-	1.7	0.0	-	0.0	0.0	-	1.7	0.3	-	0.3	0.7
D1	-	4.3	4.3	-	2.7	2.7	-	0.0	0.0	-	0.0	0.0	-	0.0	0.7
D2	-	1.3	3.3	-	0.3	1.0	-	0.0	0.0	-	0.7	0.3	-	0.7	0.3
D3	-	0.7	2.0	-	0.7	2.7	-	0.0	0.0	-	1.0	1.3	-	0.3	1.0
D4	-	1.7	3.7	-	1.0	1.7	-	1.0	0.0	-	0.0	0.0	-	0.0	0.0
D6	-	2.3	3.0	-	1.0	2.0	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
D5	-	0.3	4.0	-	0.3	1.0	-	0.3	0.0	-	0.0	0.0	-	0.7	1.0
E1	-	0.3	1.7	-	0.0	0.7	-	0.0	0.0	-	0.0	0.3	-	0.3	1.7
E2	-	1.0	-	-	1.3	-	-	0.0	-	-	0.0	-	-	0.0	-
E3	-	0.3	3.0	-	0.3	0.7	-	0.3	0.0	-	0.0	0.0	-	0.3	1.3
E4	-	1.0	1.0	-	1.0	1.0	-	0.0	0.0	-	0.0	0.0	-	0.3	0.3
E6	-	1.3	-	-	0.3	-	-	0.0	-	-	0.7	-	-	0.7	-
E5	-	4.0	-	-	0.0	-	-	0.0	-	-	0.7	-	-	0.0	-
Mean															
A	1.3	3.3	3.6	1.8	0.6	1.3	0.3	0.3	0.5	0.1	0.2	0.8	0.8	0.3	0.6
B	2.8	3.8	3.7	1.6	0.9	2.3	0.2	0.1	0.4	0.3	0.5	0.4	0.7	0.6	0.4
C	-	1.3	2.5	-	1.1	2.2	-	0.1	0.2	-	0.7	0.4	-	0.4	0.3
D	-	1.8	3.4	-	1.0	1.9	-	0.2	0.0	-	0.3	0.3	-	0.3	0.3
E	-	1.3	1.9	-	0.5	0.5	-	0.1	0.0	-	0.2	0.1	-	0.3	1.1
1	1.7	2.9	4.7	0.3	0.9	2.0	0.3	0.1	0.1	0.7	0.1	0.6	1.0	0.4	0.6
2	4.7	1.6	2.0	1.3	0.8	1.8	0.3	0.1	0.1	0.0	0.3	0.2	0.7	0.5	0.3
3	5.2	2.3	2.3	2.4	0.9	1.5	0.2	0.1	0.3	0.2	0.4	0.7	0.5	0.5	0.8
4	2.2	1.9	2.8	2.5	0.9	1.9	0.3	0.3	0.4	0.2	0.4	0.2	0.9	0.3	0.3
6	-	1.2	2.9	-	0.9	2.0	-	0.1	0.0	-	0.5	0.5	-	0.2	0.2
5	4.0	3.9	2.0	0.3	0.5	0.9	0.3	0.1	0.2	0.3	0.5	0.2	0.7	0.5	0.8
Total Mean	3.6	2.3	2.8	1.4	0.8	1.7	0.3	0.1	0.2	0.3	0.4	0.4	0.8	0.4	0.5

Table 4.4. Changes observed in the percent discolored beans, seeds with torn pericarp, and shriveled, wrinkled or dented beans (*Phaseolus vulgaris*), stored during 11.0 months in an aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 6 layers (1,...,6,5) of the pile.

(I = initial value, II = after 3.5 months, III = after 11 months)

Loc.	Discolored (%)			Torn Pericarp (%)			Shriveled (%)			Wrinkled (%)			Dented (%)		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
A1	-	4.7	0.7	-	1.0	0.0	-	9.0	3.3	-	1.7	6.3	-	8.3	4.0
A2	-	3.3	8.0	-	0.3	0.7	-	9.0	8.7	-	1.0	5.0	-	6.7	10.0
A3	5.3	8.0	0.7	0.3	0.7	1.0	6.0	6.3	4.0	5.0	4.7	2.7	7.0	10.0	5.3
A4	6.7	6.7	5.3	1.0	0.3	0.3	13.0	13.3	7.3	4.3	4.0	5.0	9.3	11.3	11.3
A6	-	10.3	8.0	-	1.7	1.3	-	8.7	12.0	-	3.3	4.3	-	8.3	11.0
A5	10.0	10.0	8.7	1.0	0.7	0.0	9.0	8.0	7.7	4.7	3.0	4.7	8.7	9.3	7.3
B1	14.3	6.7	6.3	2.0	0.7	0.0	6.7	4.3	9.3	5.3	5.7	2.3	7.3	9.0	9.3
B2	6.3	5.0	5.3	1.0	0.0	0.0	9.0	4.0	9.7	3.0	0.0	4.0	8.0	8.3	7.3
B3	6.7	6.3	6.7	0.0	0.3	0.3	8.7	10.3	8.7	3.3	4.3	6.0	8.0	9.0	10.3
B4	6.7	7.0	5.0	1.3	0.3	0.0	6.7	7.7	10.3	0.0	2.7	3.7	7.7	11.0	11.3
B6	-	5.0	-	-	0.3	-	-	7.0	-	-	2.7	-	-	6.7	-
B5	-	10.7	-	-	0.3	-	-	8.0	-	-	1.7	-	-	11.3	-
C1	-	6.7	6.3	-	0.0	0.0	-	7.7	8.0	-	4.0	5.0	-	9.3	10.3
C2	-	10.3	4.7	-	1.3	0.7	-	10.0	12.7	-	5.7	4.3	-	9.0	11.3
C3	-	6.0	2.0	-	1.0	0.0	-	9.3	8.0	-	5.3	3.7	-	9.0	5.0
C4	-	7.7	8.0	-	1.0	1.0	-	10.0	19.7	-	4.3	3.3	-	9.7	6.3
C6	-	5.7	6.0	-	2.7	1.3	-	10.3	8.7	-	0.0	5.7	-	12.0	6.0
C5	-	8.7	2.3	-	1.7	0.7	-	15.0	17.3	-	0.0	2.7	-	9.0	5.3
D1	-	6.7	6.3	-	0.3	1.0	-	7.7	12.7	-	5.0	5.0	-	10.0	8.7
D2	-	5.7	9.0	-	0.3	0.7	-	9.7	3.7	-	4.7	5.7	-	11.7	12.3
D3	-	8.7	8.3	-	0.7	1.0	-	14.7	11.7	-	3.0	4.0	-	10.7	11.7
D4	-	7.0	7.0	-	0.3	0.3	-	10.3	15.7	-	6.0	4.7	-	11.7	9.7
D6	-	5.7	2.7	-	0.3	1.3	-	9.0	13.3	-	4.7	3.7	-	9.7	6.7
D5	-	9.0	0.0	-	0.7	1.0	-	8.3	12.3	-	2.0	6.0	-	8.7	5.0
E1	-	8.0	5.3	-	0.7	1.0	-	13.3	14.3	-	0.0	2.3	-	12.3	3.7
E2	-	5.3	-	-	0.3	-	-	7.3	-	-	0.0	-	-	6.7	-
E3	-	8.3	10.0	-	2.0	1.0	-	6.7	13.7	-	2.3	2.0	-	9.3	4.0
E4	-	6.3	0.0	-	0.0	1.7	-	11.7	16.0	-	4.0	5.7	-	9.0	5.7
E6	-	4.7	-	-	0.0	-	-	8.7	-	-	2.7	-	-	8.0	-
E5	-	6.3	-	-	0.3	-	-	10.7	-	-	2.7	-	-	13.0	-
Mean															
A	7.3	7.2	5.2	0.8	0.8	0.7	9.3	9.1	7.2	4.7	3.0	4.7	8.3	9.0	8.2
B	8.5	6.8	5.8	1.1	0.3	0.1	7.8	6.9	9.5	2.9	2.9	4.0	7.8	9.2	9.6
C	-	7.5	4.9	-	1.3	0.6	-	10.4	12.4	-	3.2	4.1	-	9.7	7.4
D	-	7.1	5.6	-	0.4	0.9	-	10.0	11.6	-	4.2	4.9	-	10.4	9.0
E	-	6.5	5.1	-	0.6	1.2	-	9.7	14.7	-	2.0	3.3	-	9.7	4.5
1	14.3	6.6	5.0	2.0	0.5	0.4	6.7	8.4	9.5	5.3	3.3	4.2	7.3	9.8	7.2
2	6.3	5.9	6.8	1.0	0.4	0.5	9.0	8.0	8.7	3.0	2.3	4.8	8.0	8.5	10.2
3	6.0	7.5	5.5	0.2	0.9	0.8	7.4	9.5	9.2	4.2	3.9	3.7	7.5	9.6	7.3
4	6.7	6.9	5.1	1.2	0.4	0.7	9.9	10.6	13.8	2.2	4.2	4.5	8.5	10.5	8.9
6	-	6.3	5.6	-	1.0	1.3	-	8.7	11.3	-	2.7	4.6	-	8.9	7.9
5	10.0	8.9	3.7	1.0	0.7	0.6	9.0	10.0	12.3	4.7	1.9	4.5	8.7	10.3	5.9
Total Mean	8.7	7.0	5.3	1.1	0.7	0.7	8.4	9.2	10.8	3.9	3.0	4.4	8.0	9.3	7.9

Table 4.5. Changes observed in the percentage of beans (*Phaseolus vulgaris*) with storage related damage as well as percentage of beans that are considered unsuitable for consumption and planting, stored during 11.0 months in an aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 6 layers (1,...,6,5) of the pile.

(I = initial value, II = after 3.5 months, III = after 11 months)

Loc.	Storage Damage (%)			Inedible (%)			Unplantable (%)		
	I	II	III	I	II	III	I	II	III
A1	-	5.0	8.6	-	10.3	11.0	-	17.3	16.3
A2	-	2.0	3.0	-	5.0	12.3	-	11.3	16.3
A3	10.3	6.0	4.4	12.3	14.0	8.7	24.7	20.7	11.0
A4	5.6	6.0	5.6	9.0	10.3	13.0	22.0	24.0	19.7
A6	-	1.0	6.4	-	10.3	14.3	-	20.0	23.0
A5	4.9	6.6	8.4	9.3	8.7	14.0	20.7	21.0	17.7
B1	3.0	4.7	9.6	8.0	5.7	15.0	17.3	14.3	24.3
B2	6.3	5.7	5.3	7.7	6.3	11.0	17.7	13.0	18.3
B3	5.6	5.7	6.6	7.3	11.3	14.7	13.0	23.3	22.0
B4	4.6	3.9	5.3	4.7	9.7	12.3	13.3	18.7	19.0
B6	-	3.6	-	-	5.0	-	-	13.7	-
B5	-	7.7	-	-	10.7	-	-	23.0	-
C1	-	3.3	9.0	-	9.3	13.0	-	17.0	19.3
C2	-	2.2	3.6	-	12.7	6.7	-	19.7	11.7
C3	-	3.3	3.0	-	10.7	13.7	-	19.3	18.0
C4	-	2.0	9.0	-	6.3	15.0	-	18.3	27.0
C6	-	3.3	4.7	-	6.7	7.3	-	17.7	13.7
C5	-	4.7	2.3	-	15.3	12.3	-	26.3	21.0
D1	-	7.0	7.0	-	12.3	7.7	-	19.7	16.7
D2	-	2.3	4.6	-	10.3	8.0	-	18.3	14.3
D3	-	2.4	6.0	-	16.3	11.3	-	26.3	24.7
D4	-	3.7	5.4	-	12.0	10.0	-	19.7	17.7
D6	-	3.3	5.0	-	7.7	10.3	-	16.7	15.0
D5	-	0.9	5.0	-	7.7	8.7	-	17.7	15.0
E1	-	0.3	2.7	-	9.7	14.3	-	21.3	23.7
E2	-	2.3	-	-	5.3	-	-	13.0	-
E3	-	0.9	3.7	-	6.0	14.3	-	14.3	24.0
E4	-	2.0	1.0	-	8.7	12.3	-	18.3	24.3
E6	-	2.3	-	-	5.3	-	-	13.7	-
E5	-	4.7	-	-	9.3	-	-	17.3	-
Mean									
A	6.9	4.4	6.1	10.2	9.8	12.2	22.5	19.1	17.3
B	4.9	5.2	6.7	6.9	8.1	13.3	15.3	17.7	20.9
C	-	3.1	5.3	-	10.2	11.3	-	19.7	18.5
D	-	3.3	5.5	-	11.1	9.3	-	19.7	17.2
E	-	2.1	2.5	-	7.4	13.6	-	16.3	24.0
1	3.0	4.1	7.4	8.0	9.5	12.2	17.3	17.9	20.1
2	6.3	2.9	4.1	7.7	7.9	9.5	17.7	15.1	15.2
3	8.0	3.7	4.7	9.8	11.7	12.5	18.9	20.8	19.9
4	5.1	3.5	5.3	6.9	9.4	12.5	17.7	19.8	21.5
6	-	2.7	5.4	-	7.0	10.6	-	16.4	17.2
5	4.9	4.9	5.2	9.3	10.3	11.7	20.7	21.1	17.9
Total Mean	5.8	3.6	5.4	8.3	9.3	11.6	18.4	18.5	18.9

Table 4.6. Average storage temperatures and changes observed in some physical characteristics (moisture content, test weight and foreign material) of dry edible beans (<u>Phaseolus vulgaris</u>) stored during 9.0 months in a non-aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 4 layers (11,... ,14) of the pile.

(I = initial value, II = after 9.0 months)

Loc.	Temp. (°C)	Moisture Content (%)		Test Weight (kg/m^3)		Foreign Material (%)	
		I	II	I	II	I	II
A11	21.5	-	14.6	-	727.2	-	0.27
A12	21.6	-	14.8	-	723.5	-	0.31
A13	21.7	14.8	14.1	740.5	738.4	0.72	0.55
A14	21.7	14.4	13.7	727.6	732.5	0.55	1.39
B11	22.4	-	14.6	-	743.3	-	0.39
B12	23.4	-	15.2	-	752.8	-	0.75
B13	24.1	14.8	15.1	728.8	733.4	1.72	1.57
B14	23.5	14.4	14.2	721.1	730.1	0.55	1.02
C11	23.0	-	14.3	-	737.0	-	0.42
C12	24.0	-	14.9	-	736.7	-	0.79
C13	25.6	13.8	14.0	721.1	730.1	0.41	0.60
C14	24.2	15.8	15.2	728.6	733.4	0.27	0.37
D11	22.1	-	14.5	-	737.0	-	0.90
D12	23.3	-	14.4	-	727.6	-	0.40
D13	23.9	15.0	14.1	722.2	740.2	0.92	0.63
D14	23.7	15.0	14.6	727.3	733.8	0.65	0.78
E11	21.8	-	12	--	742.3	-	0.77
E12	22.4	-	14.5	--	736.6	-	1.43
E13	22.4	15.0	14.8	735.1	731.6	1.78	0.92
E14	23.1	15.9	13.9	736.6	737.4	0.42	0.53
Mean							
A	21.6	14.6	14.3	734.0	730.4	0.64	0.63
B	23.4	14.6	14.8	724.9	742.2	1.14	0.93
C	24.2	14.8	14.6	724.8	734.0	0.34	0.55
D	23.2	15.0	14.4	724.8	734.7	0.79	0.68
E	22.4	15.5	13.8	735.8	736.9	1.10	0.91
1	22.2	-	14.0	--	737.1	-	0.55
2	22.9	-	14.8	--	735.4	-	0.74
3	23.5	14.7	14.4	729.5	734.7	1.11	0.85
4	23.2	15.1	14.3	728.2	735.3	0.49	0.89
Total Mean	23.0	14.9	14.4	728.9	735.6	0.80	0.74

Table 4.7. Changes observed in some physical characteristics (total number of insects, number of live insects, mean hardness and percent hard-to-cook) of dry edible beans (Phaseolus vulgaris) stored during 9.0 months in a non-aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 4 layers (11,...,14) of the pile.

(I = initial value, II = after 9.0 months, III = after 11.0 months)

Loc.	Tot. # Ins. per kg		# Live Insects per kg		Mean Hardness (Newton)			Hard-to-cook (%)		
	I	II	I	II	I	II	III	I	II	III
A11	-	20.0	-	0.0	-	-	3.86	-	-	40.0
A12	-	32.6	-	0.0	-	-	2.96	-	-	29.0
A13	33.1	25.8	4.1	0.0	-	-	3.13	-	-	16.0
A14	10.0	79.3	0.0	0.0	-	3.18	3.45	-	23.0	18.0
B11	-	28.1	-	0.0	-	-	3.99	-	-	37.0
B12	-	19.3	-	0.0	-	2.54	-		23.0	-
B13	185.7	76.8	6.9	0.0	2.74	2.79	4.20	22.0	19.0	46.0
B14	13.9	60.2	13.9	0.0	-	3.11	3.03	-	26.0	22.0
C11	-	48.1	-	0.0	2.96	3.67	4.33	8.0	32.0	49.0
C12	-	34.5	-	0.0	-	-	3.35	-	-	27.0
C13	12.6	36.1	5.5	0.0	3.16	3.08	4.11	11.0	13.0	41.0
C14	10.0	21.1	5.5	0.0	2.62	-	3.45	5.0	-	22.0
D11	-	25.9	-	0.0	-	-	3.47	-	-	27.0
D12	-	32.5	-	0.0	2.74	2.74	4.09	6.0	19.0	40.0
D13	142.1	77.3	11.1	0.0	-	-	3.91	-	-	35.0
D14	28.7	35.9	6.9	0.0	-	2.81	4.40	-	23.0	51.0
E11	-	58.7	-	0.0	-	-	3.86	-	-	27.0
E12	-	91.2	-	0.0	-	-	4.01	-	-	40.0
E13	311.3	21.1	0.0	0.0	-	-	3.01	-	-	27.0
E14	30.8	28.3	17.6	0.0	-	2.93	3.42	-	21.0	27.0
Mean										
A	21.5	39.4	2.0	0.0	-	3.18	3.35	-	23.0	25.8
B	99.8	46.1	10.4	0.0	2.74	2.95	3.44	22.0	22.5	32.0
C	11.3	34.9	5.5	0.0	2.91	3.38	3.81	8.0	22.5	34.8
D	85.4	42.9	9.0	0.0	2.74	2.78	3.97	6.0	21.0	38.3
E	171.1	49.8	8.8	0.0	-	2.93	3.58	-	21.0	30.3
11	-	36.2	-	0.0	2.96	3.67	3.90	8.0	32.0	36.0
12	-	42.0	-	0.0	2.74	2.74	3.39	6.0	19.0	31.8
13	137.0	47.4	5.5	0.0	2.95	2.94	3.67	16.5	16.0	33.0
14	18.7	45.0	8.8	0.0	2.62	3.01	3.55	5.0	23.3	28.0
Total Mean	77.8	42.6	7.1	0.0	2.84	3.04	3.63	10.4	22.0	32.2

Table 4.8. Changes observed in the percent beans damaged by insects, molds or rodents and germinated or broken beans (*Phaseolus vulgaris*) stored during 9.0 months in a non-aerated bag pile in the KICUKIRO warehouse. Observations were made at 5 locations (A,...,E) and 4 layer (11,...,14) of the pile.

(I = initial value, II = value after 9 months)

Loc.	Insects (%)		Molds (%)		Rodents (%)		Germinated (%)		Broken (%)	
	I	II	I	II	I	II	I	II	I	II
A11	-	5.3	-	1.0	-	0.3	-	2.0	-	0.3
A12	-	3.7	-	0.7	-	0.3	-	1.0	-	0.3
A13	-	4.3	-	2.7	-	0.3	-	0.0	-	1.0
A14	2.0	5.0	1.7	3.3	0.0	4.0	0.7	1.0	0.3	0.0
B11	-	2.7	-	1.0	-	0.0	-	0.3	-	0.0
B12	-	0.7	-	2.0	-	0.7	-	0.7	-	1.0
B13	-	6.7	-	2.3	-	0.0	-	0.3	-	1.0
B14	-	5.0	-	3.3	-	0.3	-	0.7	-	0.3
C11	-	3.7	-	2.3	-	0.3	-	0.3	-	0.3
C12	-	4.7	-	4.0	-	0.0	-	0.7	-	0.3
C13	1.3	3.7	3.3	1.7	0.0	0.0	0.7	0.7	0.3	0.7
C14	2.3	2.0	2.7	3.7	0.0	0.3	1.0	0.7	0.3	0.7
D11	-	1.7	-	2.0	-	0.0	-	0.3	-	0.7
D12	-	7.3	-	2.3	-	0.0	-	0.0	-	0.3
D13	-	6.0	-	2.3	-	0.0	-	0.3	-	1.0
D14	-	4.0	-	5.7	-	0.3	-	0.7	-	0.3
E11	-	3.7	-	1.3	-	0.7	-	0.0	-	0.7
E12	-	6.3	-	3.3	-	0.3	-	0.3	-	0.7
E13	-	3.7	-	0.7	-	0.3	-	0.3	-	0.7
E14	4.3	4.0	2.0	2.7	0.3	0.7	0.7	0.3	0.7	0.3
Mean										
A	2.0	4.6	1.7	1.9	0.0	1.2	0.7	-	0.3	0.4
B	-	3.8	-	2.2	-	0.3	-	0.5	-	0.6
C	1.8	3.5	3.0	2.9	0.0	0.2	0.9	0.6	0.3	0.5
D	-	4.8	-	3.1	-	0.1	-	0.3	-	0.6
E	4.3	4.4	2.0	2.0	0.3	0.5	0.7	-	0.7	0.6
11	-	3.4	-	1.5	-	0.3	-	0.6	-	0.4
12	-	4.5	-	2.5	-	0.3	-	0.5	-	0.5
13	1.3	4.9	3.3	1.9	0.0	0.1	0.7	0.3	0.3	0.9
14	2.9	4.0	2.1	3.7	0.1	1.1	0.8	0.7	0.4	0.3
Total Mean	2.5	4.2	2.4	2.4	0.1	0.4	0.8	0.5	0.4	0.5

Table 4.9. Changes observed in the percent discolored beans, beans with torn pericarp and shriveled, wrinkled or dented beans (Phaseolus vulgaris) stored during 9.0 months in a non-aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 4 layers (11,...,14) of the pile.

(I = initial value, II = value after 9 months)

Loc.	Discolored (%)		Torn pericarp (%)		Shriveled (%)		Wrinkled (%)		Dented (%)	
	I	II	I	II	I	II	I	II	I	II
A11	-	4.0	-	0.7	-	5.7	-	8.0	-	8.0
A12	-	4.7	-	0.3	-	8.3	-	3.3	-	10.0
A13	-	4.0	-	0.3	-	4.7	-	7.0	-	10.7
A14	7.0	5.0	0.0	0.3	18.7	14.0	3.0	3.0	7.0	11.0
B11	-	8.7	-	0.7	-	7.0	-	2.7	-	9.0
B12	-	5.3	-	0.7	-	9.0	-	4.0	-	10.3
B13	-	1.7	-	0.7	-	16.0	-	3.3	-	10.0
B14	-	8.0	-	0.0	-	9.7	-	5.0	-	11.0
C11	-	7.7	-	0.0	-	8.0	-	4.0	-	11.0
C12	-	4.7	-	0.0	-	9.0	-	6.7	-	9.7
C13	10.3	5.0	0.7	0.3	9.3	8.0	6.0	2.0	10.3	12.0
C14	7.7	4.3	1.3	0.0	11.7	10.7	4.0	5.3	10.3	12.7
D11	-	4.0	-	1.0	-	12.7	-	4.7	-	10.0
D12	-	4.0	-	0.7	-	7.0	-	6.0	-	6.0
D13	-	7.0	-	0.0	-	8.0	-	6.0	-	10.0
D14	-	3.7	-	1.3	-	8.3	-	2.3	-	16.7
E11	-	4.0	-	1.3	-	12.0	-	3.3	-	7.0
E12	-	6.0	-	0.3	-	18.0	-	1.0	-	9.3
E13	-	4.3	-	0.0	-	10.3	-	2.7	-	9.0
E14	6.0	6.7	2.0	1.3	13.7	14.7	2.6	1.3	10.3	14.3
Mean										
A	7.0	4.4	0.0	0.4	18.7	8.2	3.0	5.3	7.0	9.9
B	-	5.9	-	0.5	-	10.4	-	3.8	-	10.1
C	9.0	5.4	1.0	0.1	10.5	8.9	5.0	4.5	10.3	11.4
D	-	4.7	-	0.8	-	9.0	-	4.8	-	10.7
E	6.0	5.3	2.0	0.7	13.7	13.8	2.6	2.1	10.3	9.9
11	-	5.7	-	0.7	-	9.1	-	4.5	-	9.0
12	-	4.9	-	0.4	-	10.3	-	4.2	-	9.1
13	10.3	4.4	0.7	0.3	9.3	9.4	6.0	4.2	10.3	10.3
14	6.9	5.5	1.1	0.6	14.7	11.5	3.2	3.4	9.2	13.1
Total Mean	7.8	5.1	1.0	0.5	13.4	10.1	3.9	4.1	9.5	10.4

Table 4.10. Changes observed in the percent of beans (*Phaseolus vulgaris*) with storage related damage as well as beans that are considered unsuitable for consumption and planting stored during 9.0 months in a non-aerated bag pile in the KICUKIRO warehouse. Observations made at 5 locations (A,...,E) and 4 layers (11,...,14) of the pile.

(I = initial value, II = value after 9 months)

Loc.	Storage Damage (%)		Inedible (%)		Unplantable (%)	
	I	II	I	II	I	II
A11	-	8.6	-	13.7	-	17.3
A12	-	5.7	-	14.3	-	18.3
A13	-	7.3	-	11.7	-	17.0
A14	4.4	13.3	9.0	11.0	19.0	18.0
B11	-	4.0	-	14.7	-	18.7
B12	-	4.1	-	15.7	-	19.7
B13	-	9.3	-	16.3	-	26.7
B14	-	9.3	-	13.3	-	18.3
C11	-	6.6	-	15.3	-	21.7
C12	-	9.4	-	15.3	-	22.7
C13	5.3	6.1	11.0	13.0	19.0	18.7
C14	6.0	6.7	12.7	13.7	21.3	21.3
D11	-	4.0	-	12.0	-	20.0
D12	-	9.6	-	14.7	-	18.7
D13	-	8.6	-	11.3	-	21.0
D14	-	10.7	-	9.7	-	18.3
E11	-	5.7	-	6.3	-	21.3
E12	-	10.2	-	15.3	-	26.0
E13	-	5.0	-	11.3	-	18.3
E14	7.3	7.7	11.3	10.3	21.0	16.0
Mean						
A	4.4	8.7	9.0	12.7	19.0	17.7
B	-	6.7	-	15.0	-	20.9
C	5.7	7.2	11.9	14.3	20.2	21.1
D	-	8.2	-	11.9	-	19.5
E	7.3	7.2	11.3	13.3	21.0	20.4
11	-	5.8	-	14.4	-	19.8
12	-	7.8	-	15.1	-	21.1
13	5.3	7.3	11.0	12.7	19.0	20.3
14	5.9	9.5	11.0	11.6	20.4	18.4
Total Mean	5.8	7.6	11.0	13.4	20.1	19.9

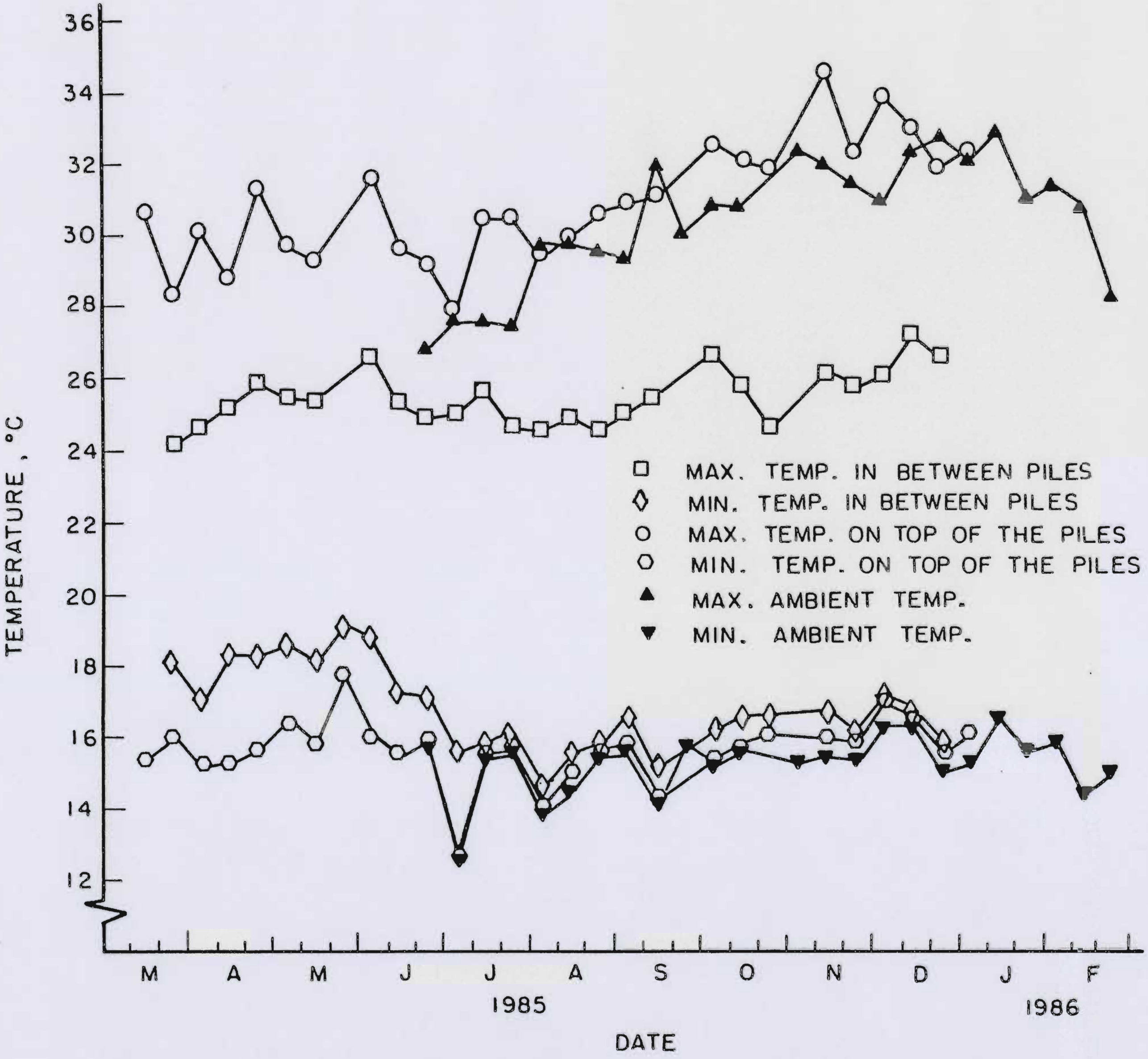


Figure 4.3. Ten-day mean maximum and minimum ambient temperatures and temperatures in between and on top of stacks stored at the KICUKIRO warehouse (March, 1985-February 1986).

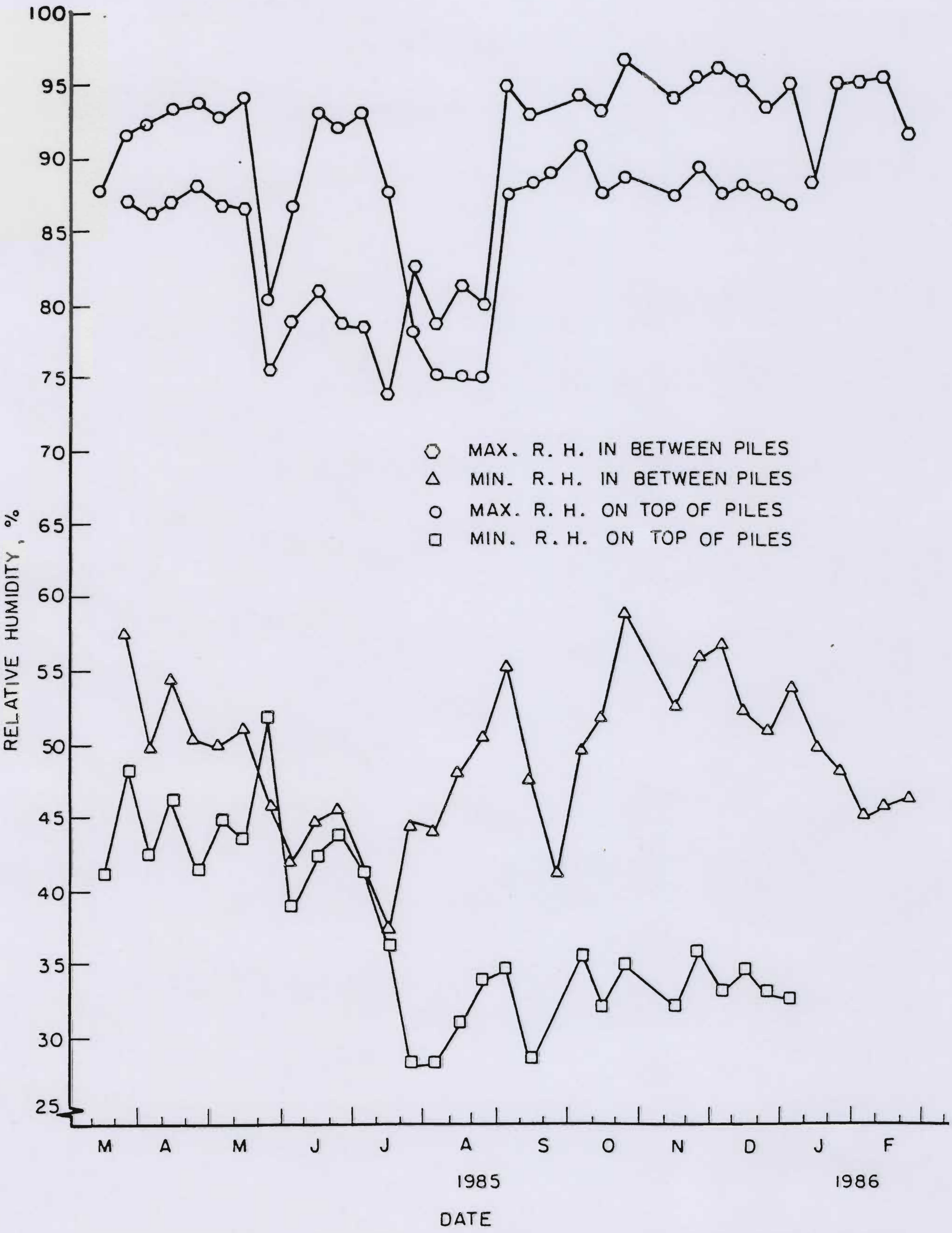


Figure 4.4. Ten-day mean maximum and minimum relative humidities in between and on top of stacks stored in the KICUKIRO warehouse (March 1985 - February 1986).

occurring in the immediate neighborhood of the duct and the higher temperatures occurring on the lateral surfaces and the layer just under the top layer. In this case the vertical gradient is steeper than the lateral ones. This distribution pattern indicates strongly that the air flow in the pile is mainly in a horizontal direction and perpendicular to the duct. Apparently very little horizontal air reaches or passes through the upper layers of the stack.

The uniformity of the temperature distribution can be measured with the maximum temperature difference observed between positions in a pile or by the standard deviation of the mean storage temperatures. These parameters are 4.7 and 1.5°C, respectively, for the AP and 4.1 and 1.1°C, respectively, for the NAP. It can therefore be concluded that this aeration system did not improve the overall uniformity of the temperature distribution.

The average initial moisture content of the AP (15.4%) (Table 4.1) was 0.5% higher than for the NAP (14.9%) (Table 4.6). This is probably because the beans of the latter pile were purchased several weeks later than the others and, therefore had had more time to dry. In both stacks the average moisture content decreased over time: 0.7% in the AP and 0.5% in the NAP. These decreases are in general more important in the top layers than in the rest of the pile. This is because the top layers are exposed to higher temperatures. Fig. 4.3 shows large temperature gradients within the warehouse, with the higher temperatures occurring near the ceiling of the warehouse and the lower ones in between the piles. The moisture content distributions in both piles at the end of the storage period show patterns that follow closely the temperature distributions, with higher temperatures resulting in lower moisture contents and vice versa.

During the first three months the aeration system was switched on every night in order to cool the pile as quickly as possible. The cool air also had a high relative humidity (90-95%), so some of the bags (especially those in the immediate vicinity of the duct (C1 and D1)) gained in moisture content. A higher moisture content entails the risk for fungal growth and spoilage. Therefore, as soon as the pile is cooled down, aeration should be limited to a strict minimum.

Both piles contained a large number of live and dead insects at the beginning of the storage period (Tables 4.2 and 4.7). This illustrates the necessity to have an efficient fumigation program. These applications were successful since no live insects were found in the final samplings. Also incubation tests on about 15 final samples from these piles did not yield live bruchids.

It was, however, not unusual to find live psocids in the samples. Psocids (Order 'Psocoptera'), also known as book lice are tiny, often wingless, and rather colorless insects which do not feed on or cause damage in grain to any significant degree. They are primarily mold feeders whose development is favored by a warm, damp environment. They are in fact an indicator of humid conditions and even of molds.

The damage analysis results (Tables 4.3, 4.4, 4.5, 4.8, 4.9 and 4.10) show that none of the damage categories, including the percentages of beans with storage related damage and those unfit for consumption or planting changed significantly during the storage period. There is also no indication of significant differences between the piles for any of these factors. It should, however, be mentioned that the relatively high percentage of beans considered unfit for consumption (10%) or planting purposes (20%) are somewhat disturbing. It should be investigated if they can be removed from the stock before storage.

The last quality characteristics to look at are the hardness parameters (Tables 4.2 and 4.7). The AP was monitored for 11.0 months, while the NAP remained only 9.0 months in storage. To have a more valid base of comparison, it was decided to keep the NAP samples in the laboratory (which has the same temperature conditions as the interior part of the NAP) for another two months and to remeasure their instrumental hardness. It can then be seen that %HTC beans had surpassed the 30% level in both piles before 11.0 months of storage, with a higher value for the AP (39.3%) than the NAP (32.2%). This may indicate that the hardening in the NAP was just starting, while it had begun a couple of months earlier in the AP. It is worthwhile noting that in the AP, the position and layer with the highest %HTC scores (position A and layer 6, resp.) also have the highest average temperature. Further clear cut conclusions on the effect of the storage environmental conditions on the hardening of the beans are at this point difficult to make because of the continuously changing moisture and temperature conditions and the limited amount of hardening that actually took place.

4.3. Roof Insulation Experiment

One convenient way of lowering the temperatures within a warehouse could be the reduction of the heat load on the building through improved insulation combined with the removal of the warm air using a forced or natural ventilation system. Previous observations have shown that the temperatures above the piles and near the ceiling are much higher than those near the floor. The metal roof with its translucent plastic sections is obviously the area through which most of the heat enters the building. The potential benefit of installing roof insulation can be predicted using heat balance calculations. This approach requires temperature versus time measurements at different locations near insulated and non-insulated sections of the roof.

4.3.1. Methodology

Three sections of the roof above a large pile were insulated with 0.7 cm thick plywood boards (Fig. 4.5). Because the long axis of the building runs in a north-south direction, it was decided to insulate different parts of the roof having different exposures to the sun. Sections A and B each covered a metal roof area of 2.0 x 1.5 m, while section C covered a 1.0 x 1.5 m translucent plastic area. The plywood sheets were covered with a layer of white paint on both surfaces and suspended from the roof construction with ropes. An air space of 15.0 cm was left between the roof and the plywood. Fig. 4.5 also shows the location of the thermocouples. In total, 24 thermocouples were installed and connected to a timer controlled temperature recorder (Honeywell Model 112). The recorder could scan all 24 thermocouples within a 3 minute period. The timer was adjusted so that the recorder measured the temperatures at one hour intervals. The insulation sheets and the thermocouples (TC) were distributed as follows:

Section A: under a metal section, at the east side of the building:

TC #1: attached to the roof
TC #2: halfway between the roof and the insulation
TC #3: attached to top side of insulation sheet
TC #4: attached to lower side of insulation sheet

Non-insulated metal section, at east side of the building:

TC #5: attached to the roof
TC #6: at 20 cm from roof

Section A: under a metal section, at the west side of the building:

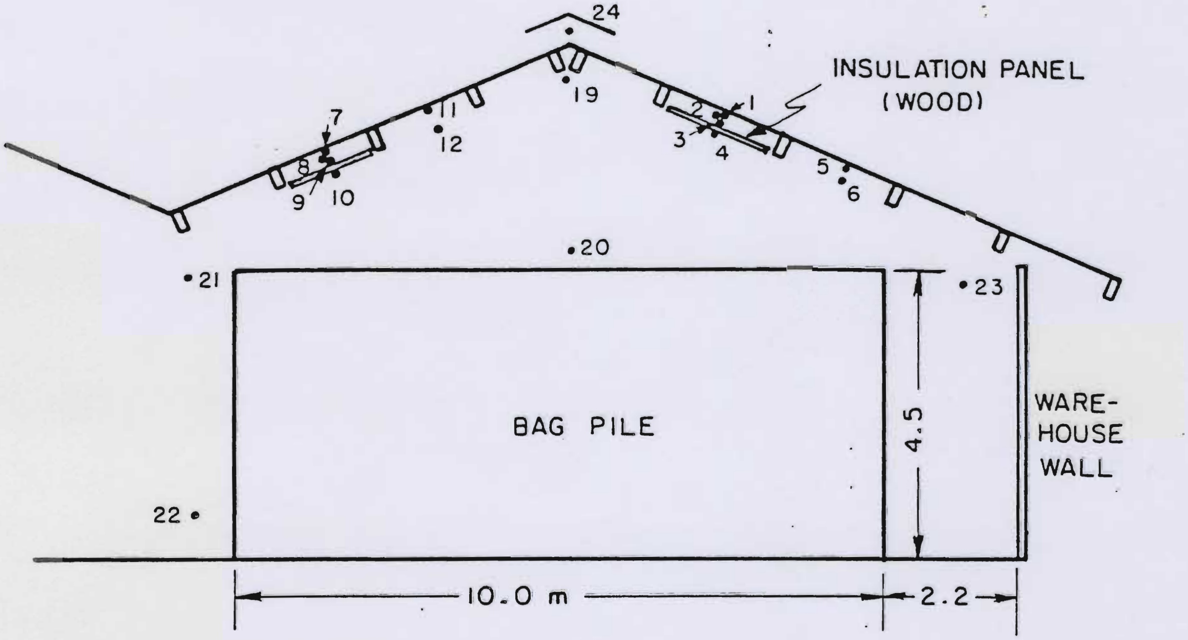
TC #7: attached to the roof
TC #8: halfway between the roof and the insulation
TC #9: attached to top side of insulation sheet
TC #10: attached to lower side of insulation sheet

Non-insulated metal section, at west side of the building:

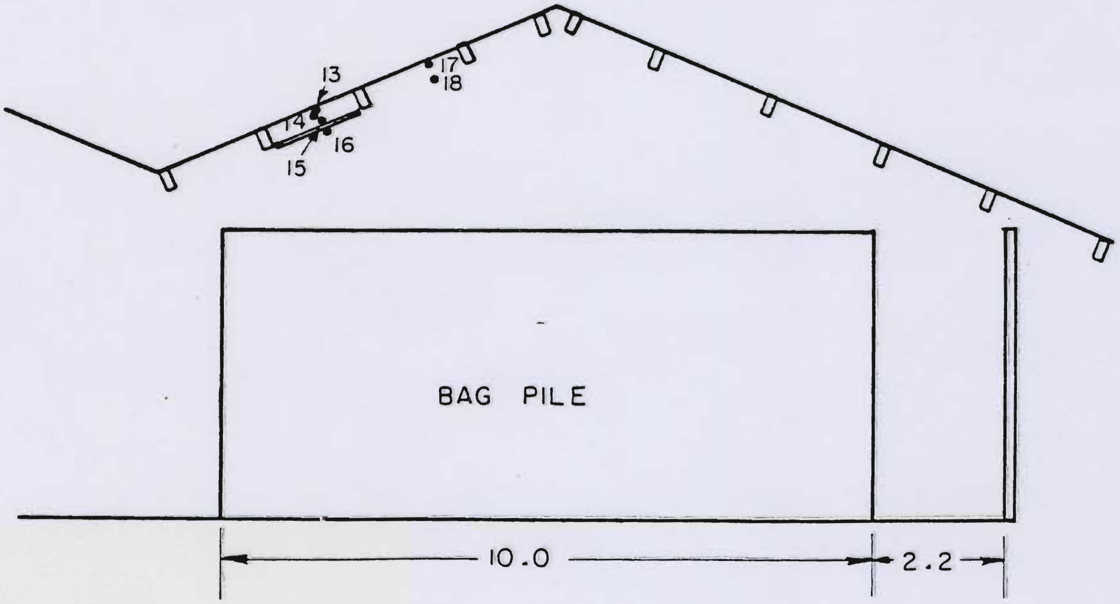
TC #11: attached to the roof
TC #12: at 20 cm from roof

Section B: under a translucent plastic section, at the west side of the building:

TC #13: attached to the roof
TC #14: halfway between the roof and the insulation
TC #15: attached to top side of insulation sheet
TC #16: attached to lower side of insulation sheet



A. INSULATION PANELS AND THERMOCOUPLES UNDER METAL SECTIONS OF THE ROOF.



B. INSULATION PANELS AND THERMOCOUPLES UNDER TRANSLUCENT PLASTIC SECTION OF THE ROOF.

Figure 4.5. Roof insulation study: experimental setup with locations of insulation panels and thermocouples (KICUKIRO warehouse).

Table 4.11. Average hourly temperatures (°C) for 5 days (Feb. 14-18, 1987) for the roof insulation experiments at the KICUKIRO warehouse. Thermocouple locations defined in Fig. 4.5 and text.

Thermocouple Number	1	2	3	4	5	6	7	8	9	10	11	12
Hour												
1	15.8	18.5	18.2	18.8	16.7	19.3	15.6	18.2	17.9	18.8	16.6	19.2
2	15.8	18.2	17.9	18.4	16.6	19.0	15.5	17.9	17.6	18.4	16.4	19.0
3	15.5	17.9	17.8	18.3	16.4	18.9	15.4	17.7	17.5	18.2	16.3	18.8
4	15.3	17.8	17.6	18.1	16.0	18.8	15.2	17.5	17.3	18.0	15.9	18.5
5	15.0	17.2	17.1	17.5	15.6	17.9	15.0	16.9	16.7	17.5	15.6	17.7
6	14.6	17.1	17.0	17.4	15.4	18.0	14.4	17.0	16.5	17.4	15.3	17.8
7	19.4	18.9	18.9	18.9	20.2	19.1	16.2	17.8	17.4	18.1	17.0	18.9
8	34.7	26.8	26.9	25.6	33.3	23.9	22.7	22.3	21.2	21.5	24.1	24.4
9	45.2	34.5	35.4	33.8	41.8	29.9	33.1	29.3	28.7	27.9	34.2	32.9
10	50.1	35.0	38.1	36.4	42.2	27.5	41.5	31.2	34.0	31.8	40.3	31.3
11	55.2	40.0	41.6	39.5	47.9	31.2	49.2	35.1	38.3	35.5	47.3	35.9
12	48.7	35.1	37.5	36.1	40.8	27.9	47.6	33.2	37.5	34.6	44.5	31.5
13	46.3	38.0	38.3	37.5	40.9	29.8	45.2	33.8	38.2	35.8	43.6	31.9
14	39.9	32.4	34.4	33.9	36.8	29.1	42.1	32.7	35.5	33.6	40.8	31.5
15	36.9	31.0	32.4	32.1	33.4	26.9	40.5	31.1	34.2	32.1	37.9	28.6
16	27.3	26.5	27.4	27.3	26.4	25.6	27.9	26.8	28.0	27.9	27.8	26.2
17	24.2	24.4	25.0	25.2	23.9	23.9	27.6	25.2	26.7	26.2	26.4	24.0
18	20.3	22.4	22.5	22.9	21.0	22.7	20.3	22.3	22.5	23.3	20.8	22.8
19	18.3	20.6	20.6	21.1	19.4	21.4	18.2	20.5	20.4	21.3	19.2	21.5
20	17.6	20.7	20.2	20.7	18.7	21.3	17.5	20.3	20.0	20.7	18.5	21.3
21	17.6	20.1	19.9	20.3	18.5	20.7	17.2	19.7	19.5	20.3	18.2	20.8
22	16.7	19.6	19.3	20.0	17.5	20.3	16.7	19.4	19.0	19.7	17.5	20.2
23	16.0	19.2	18.7	19.4	16.7	20.0	15.8	18.9	18.4	19.3	16.6	19.7
24	15.9	18.5	18.3	18.8	16.7	19.4	15.7	18.2	17.9	18.8	16.5	19.0

Thermocouple Number	13	14	15	16	17	18	19	20	21	22	23	24
Hour												
1	15.6	18.4	17.9	18.7	16.4	19.3	19.4	19.7	19.8	19.7	20.1	17.3
2	15.5	18.4	17.7	18.5	16.5	19.1	19.2	19.5	19.6	19.5	19.8	16.9
3	15.4	17.9	17.7	18.3	16.3	18.9	18.9	19.3	19.3	19.1	19.5	16.7
4	15.4	17.8	17.4	18.0	16.0	18.7	18.7	19.0	19.0	19.0	19.4	16.6
5	15.0	17.1	16.9	17.4	15.5	17.9	17.9	18.3	18.5	18.2	18.7	16.3
6	14.4	17.1	16.7	17.3	15.2	17.8	17.9	18.4	18.5	18.3	18.5	15.5
7	17.2	18.7	18.4	18.2	17.5	19.3	19.2	19.3	19.1	19.1	19.6	17.6
8	23.4	23.7	23.4	22.0	24.7	25.0	25.5	22.8	21.2	21.6	22.2	22.8
9	38.7	32.7	34.1	26.9	36.9	33.4	33.8	26.3	24.0	24.6	25.0	27.0
10	48.0	34.2	40.9	32.9	43.9	32.6	31.8	26.5	25.5	26.1	25.9	32.1
11	57.4	39.0	45.7	37.0	48.6	35.8	37.5	29.1	27.0	28.2	27.0	34.7
12	56.3	34.4	45.0	36.1	49.9	34.5	34.3	28.4	27.4	28.2	27.1	35.1
13	53.6	36.5	45.0	36.7	43.1	31.7	30.2	28.1	27.6	28.4	27.1	32.5
14	48.5	35.1	40.7	34.4	37.3	32.8	32.8	28.4	27.5	28.1	27.4	32.6
15	45.9	32.9	38.9	32.8	37.6	28.7	28.4	27.6	27.2	27.6	26.9	33.6
16	30.7	27.7	29.8	28.1	27.2	26.2	26.1	25.9	26.0	26.1	25.7	26.6
17	29.7	26.2	28.7	26.6	28.7	24.6	24.2	24.6	24.6	24.7	24.5	25.3
18	20.6	22.3	22.8	23.3	21.6	22.8	22.8	23.2	23.1	23.2	23.2	20.9
19	18.1	20.7	20.5	21.3	19.6	21.4	21.5	22.0	22.0	21.9	22.1	19.4
20	17.6	20.5	20.0	20.7	19.0	21.3	21.3	21.7	21.7	21.6	22.1	19.2
21	17.3	20.0	19.5	20.3	18.5	20.8	21.0	21.3	21.2	21.1	21.5	18.9
22	16.5	19.4	19.1	19.8	17.9	20.4	20.4	20.8	20.9	20.6	21.0	18.2
23	15.9	18.9	18.5	19.2	17.3	19.8	19.9	20.5	20.3	20.2	20.7	17.4
24	15.8	18.5	18.2	18.8	17.0	19.2	19.3	19.8	19.7	19.7	20.0	17.1

Non-insulated translucent plastic section, at west side of the building:

TC #17: attached to the roof
TC #18: at 20 cm from roof

In addition the following ambient temperatures were measured:

TC #19: just under the ridge of the roof
TC #20: 20 cm above the bag pile
TC #21: near top of the pile (100 cm west of pile)
TC #22: near bottom of the pile (100 cm west of pile)
TC #23: near top of the pile (100 cm east of pile)
TC #24: ambient outside roof temperature

4.3.2. Results and Discussion

Temperature results summarized for 5 days (February 14 to 18, 1987) are shown in Table 4.11 according to temperature locations identified in Fig. 4.5. Several temperatures from Section A (Fig. 4.5) on the east side of the building are plotted in Fig. 4.6. Locations 1, 4 and 5 under the roof or the insulation are included along with locations near the top (20) and bottom (22) of the pile. The plot shows a significant rise in temperature under the roof starting at 7 a.m. and cooling down again at 5 p.m. (1700 hours). The temperature under the roof insulation panel (location 4) was approximately 15°C cooler (40 vs. 55°C) than under the roof above the insulation (location 1) and approximately 10°C cooler (40 vs. 50°C) than under the roof in a non-insulated section (location 5).

Plots for Section A on the west side of the building (Fig. 4.7) and Section B on the west side of the building under the translucent plastic roof material (Fig. 4.8) show results similar to Fig. 4.6. The peak temperature rise beneath the translucent plastic is somewhat higher than under the metal (20°C rise under plastic vs. 15°C rise under metal) as expected.

These results show that insulation could reduce the temperature at the inside surface of the roof which in turn would reduce heat gain of the interior space. Since the three insulated panels in this experiment cover only a very small portion of the total roof area, they have little effect on the total warehouse environment. Therefore, roof temperature measurements give an indication of the effect that could be expected by addition of roof insulation, but the actual roof temperatures measured were still affected by the temperature of the interior space. Thus, it is probable that if the total roof area were covered with insulation, temperatures measured on the underside of the insulation would be even lower than were observed in this experiment. Further analysis involving a heat balance on the total system would be required to confirm this estimate.

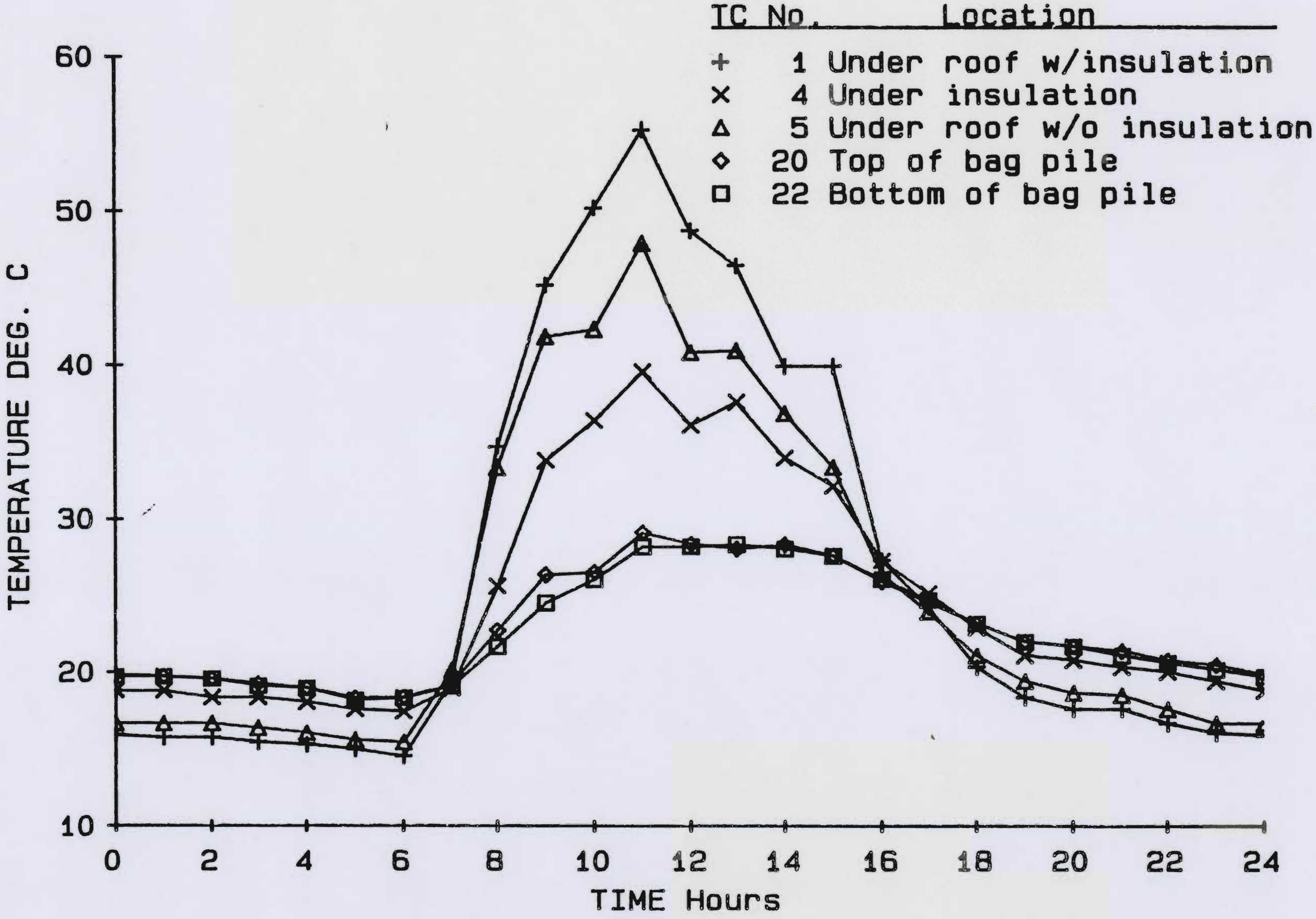


Figure 4.6. Five-day average temperatures under a metal section of roof (Section A, East Side, Figure 4.5) and at top and bottom of pile (KICUKIRO Warehouse, February 14-18, 1987).

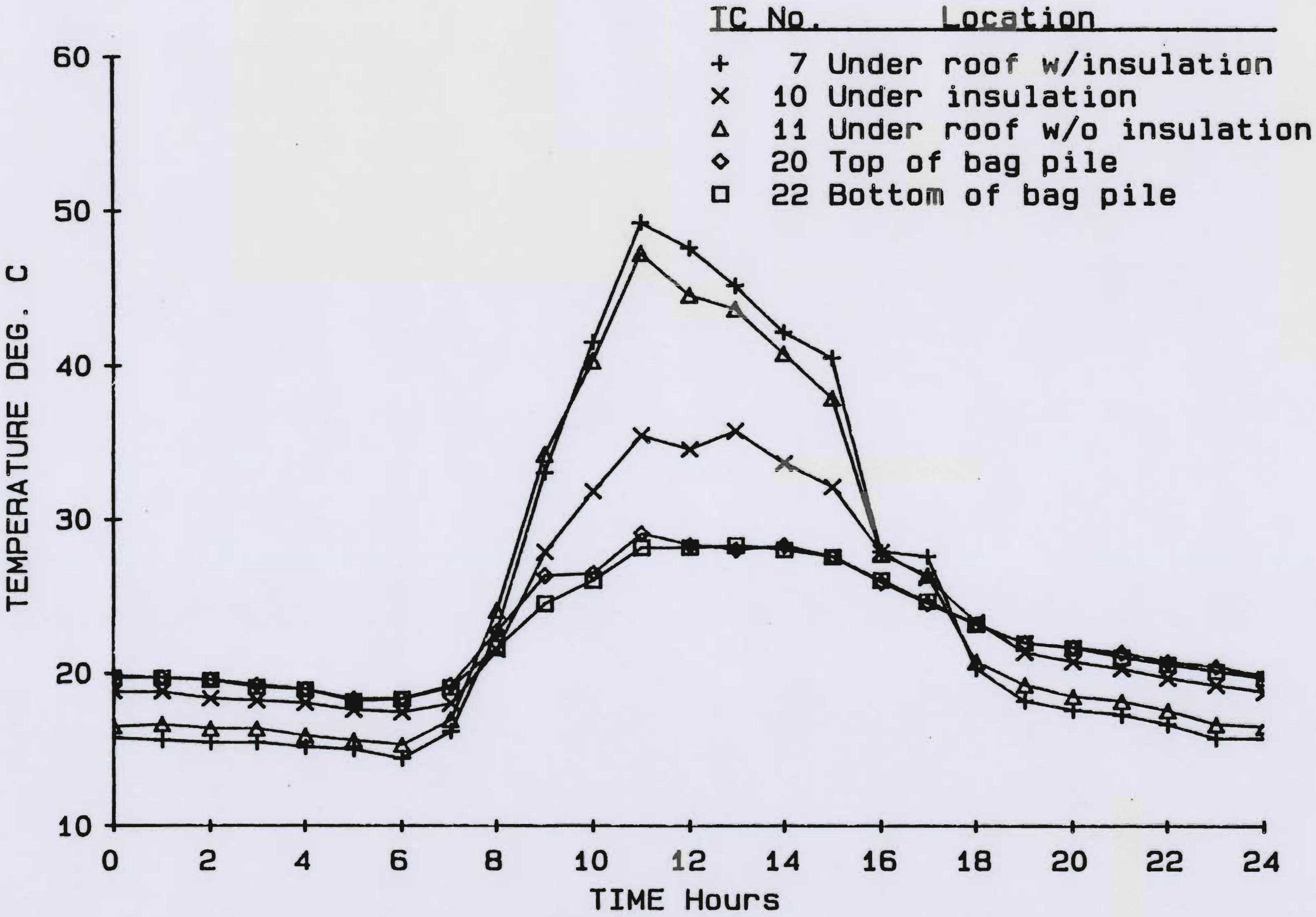


Figure 4.7. Five-day average temperatures under a metal section of roof (Section A, West Side, Figure 4.5) and at top and bottom of pile (KICUKIRO warehouse, February 14-18, 1987).

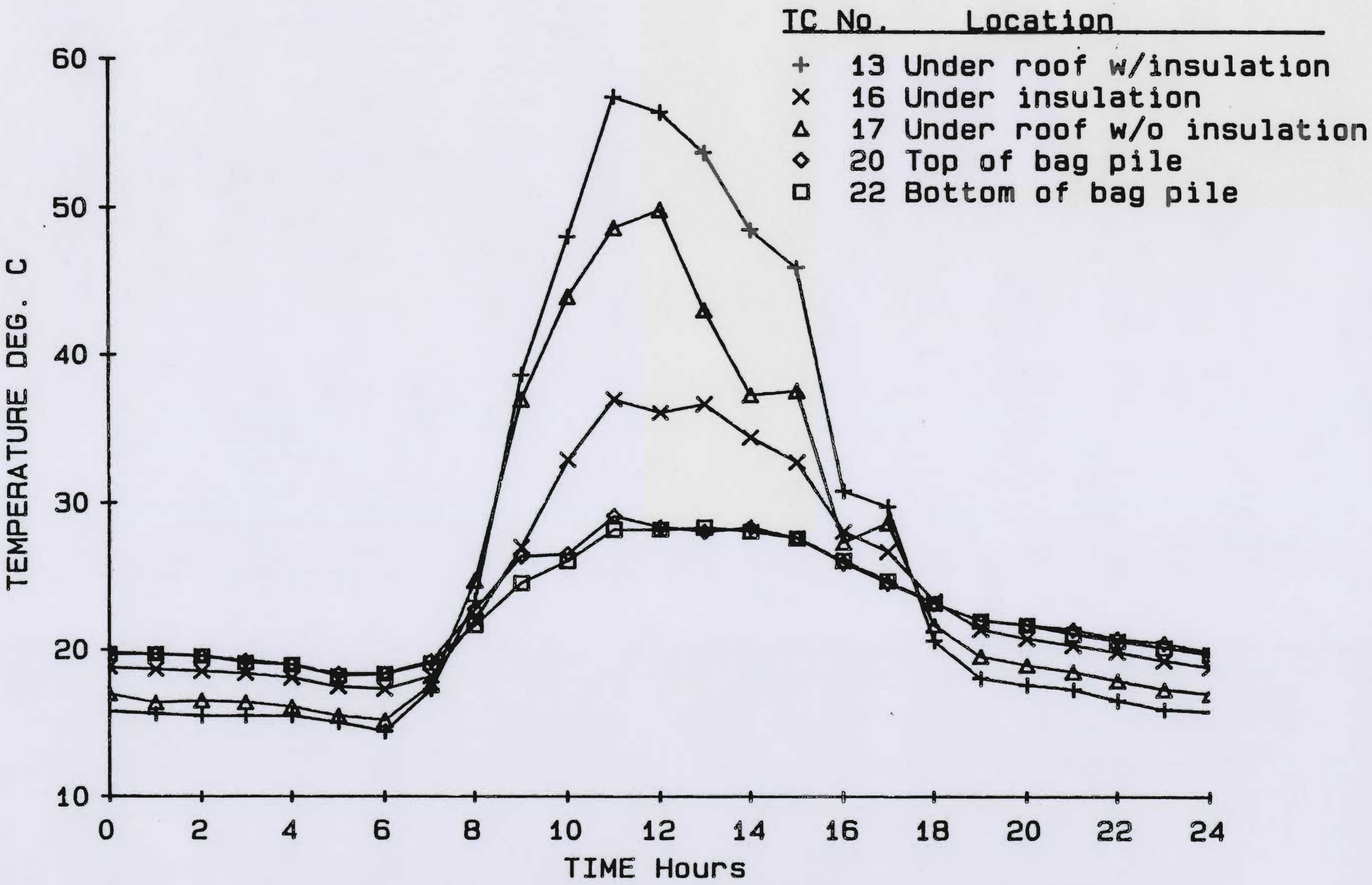


Figure 4.8. Five-day average temperatures under a translucent section of roof (Section B, West Side, Figure 4.5) and at top and bottom of pile (KICUKIRO warehouse, February 14-18, 1987).

Temperatures measured near the top (20) and bottom (22) of the pile indicate that the interior rises about 10°C from the minimum reached around 5 a.m. to a maximum which occurs around 11 a.m. to 2 p.m. each day and then gradually decreases to the minimum the following morning. These results show that the heat load on the roof results in a significant increase in the interior temperature each day.

The temperatures measured immediately under the roof (locations: 1 and 5 in Fig. 4.6; 7 and 10 in Fig. 4.7; 13 and 16 in Fig. 4.8) decreased 3 or 4°C below the interior temperatures during the night-time hours. This suggests additional potential for cooling the interior by mechanical ventilation which draws in night time air. It is conceivable that by using a combination of insulation, natural ventilation and possibly mechanical ventilation it would be possible to maintain the interior warehouse temperature below 20°C throughout the day.

4.4. Effect of Aeration on Insect Development

Aeration and the resulting reduction of grain temperatures are often described as an effective means of controlling stored grain insect populations (Navarro & Calderon, 1982). However, the large pile aeration experiment did not clearly demonstrate this potential under the climatic conditions prevailing in Rwanda. Therefore, it was thought useful to design a small-scale experiment to verify these claims.

In the larger framework of training counterpart staff (Objective 5), this experiment seemed to be a very appropriate research exercise for which a beginning researcher could bear prime responsibility and was conducted in that spirit. This experiment started on January 15, 1987 and is projected to take at least six months to complete. As no results are available at this time, the discussion will be limited to the methodology used.

4.4.1. Methodology

The experimental setup consisted of 6 metal drums each containing 129 kg of beans (13.0% M.C.). The top lid of the drums had been removed, and the drums were raised off the floor with their bottom sides on three concrete blocks. Each drum had a false perforated floor fitted into it, and three of the drums were connected with galvanized metal pipes (5 cm (2.0") diam.) to a common fan (Fig. 4.9). The airflow to each individual drum was regulated with a valve. The rates were adjusted so that each (bean filled) drum received the same amount of airflow (0.8 m^3/min (30 cfm)). The fan motor is connected to an electric timer, which is adjusted such that aeration is provided between midnight and 6:00 a.m.

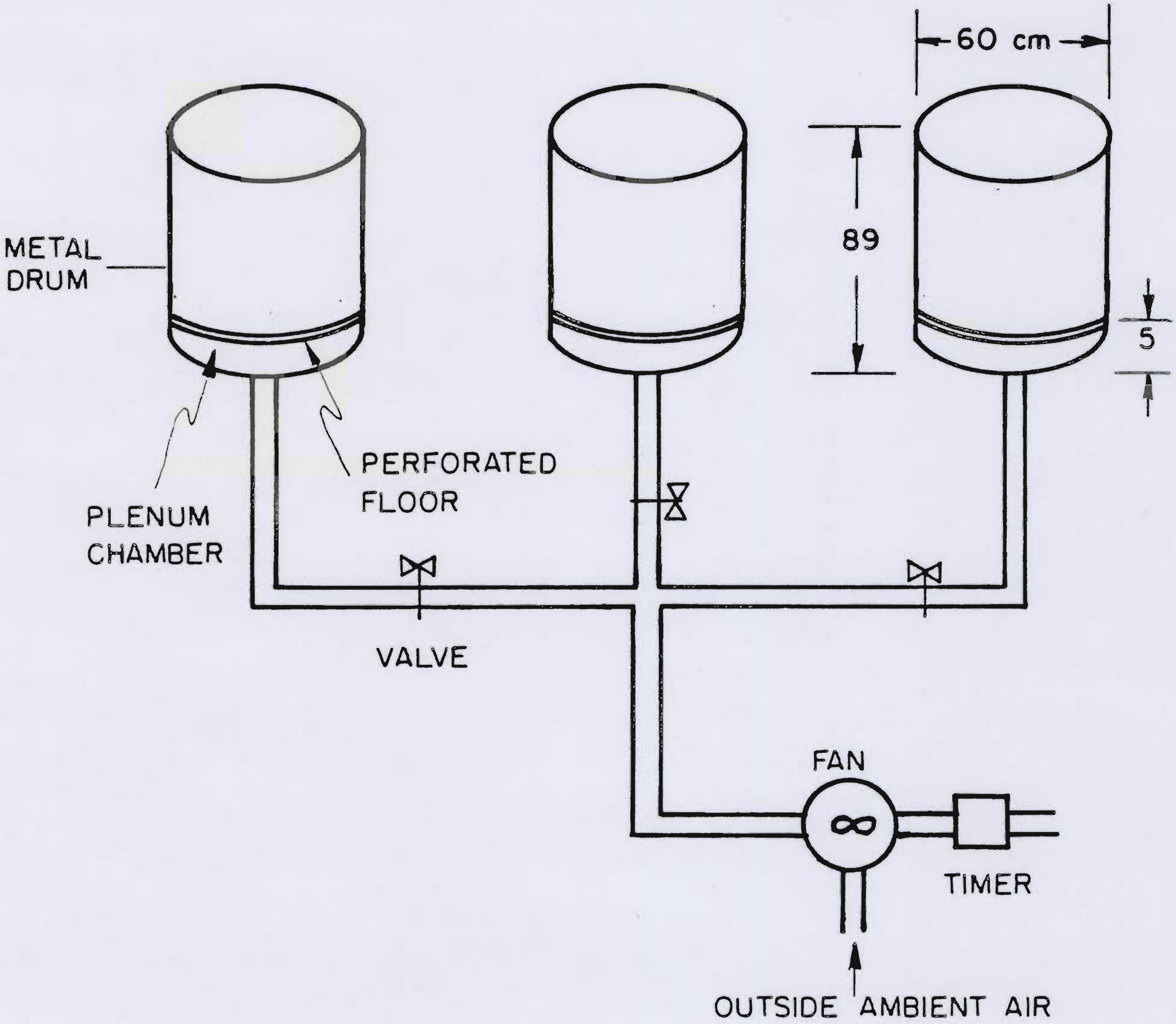


Figure 4.9. Schematic diagram of apparatus for the aeration portion of the study to determine the effect of aeration on insect development.

The beans used for this experiment were a mixture of 720 kg of beans stored underground for 12 months (see Chapter 7) supplemented with 54 kg of dry beans bought on the local market. Since the only factor to be studied was insect development, the mixing of these two lots was not considered critical. After thoroughly mixing the beans, the whole batch was fumigated with Phostoxin to eliminate all insect stages. The beans were then divided in 6 batches of 129 kg. Each batch was further divided in 3 equal parts of 43 kg and mixed with 65 couples of 7 day old adult _Acanthoscelides obtectus_ specimens before being placed in one of the drums. These insects had been reared at the project's satellite laboratory at I.S.A.R. A thermocouple was inserted within each layer of beans added.

The aeration application started on January 27. Samples (300 g) are being drawn from three layers (top, middle and bottom) of each drum at one month intervals and analyzed for the total number of insects per kg, the number of live insects per kg and the percent beans damaged by insects. To facilitate the layered sampling, a standard slotted probe was modified by covering all but the first slot with duct tape.

4.5. Differential Insect Penetration Resistance of Bag Materials

At present two types of bags are used to store beans and sorghum in the government warehouses: jute bags and plastic woven bags. The question was raised as to which one is better and should be used in the future. One of the factors to examine is what bag material forms the better barrier to bruchids (_Acanthoscelides obtectus_ and _Zabrotes subfasciatus)_. This is important because reinfestations from outside after fumigation and the proliferation of insects within a pile may be slowed down in piles constructed with bags possessing higher resistance to insect penetration.

4.5.1. Methodology

The materials selected for comparison of their insect penetration resistance properties were woven fabrics of jute and polyethylene fibers, and polyethylene plastic sheeting. The woven fabrics (jute and polyethylene fibers) contain small openings or perforations due to the way they are constructed. The polyetheylene plastic sheeting is a continuous piece of material without perforations. The basic setup was to place beans and adult female insects in a glass quart mason jar, cover the jar with one of the materials, and then connect the opening of a second jar containing male insects to the covered opening of the first (Fig. 4.10). At certain time intervals the number of male insects that had penetrated through the material was counted.

This experiment consisted of three treatments (type of material), two objects (insect species) and three replications. Eighteen quart mason jars were filled with dry beans which had been fumigated just prior to this experiment. They were labeled from one

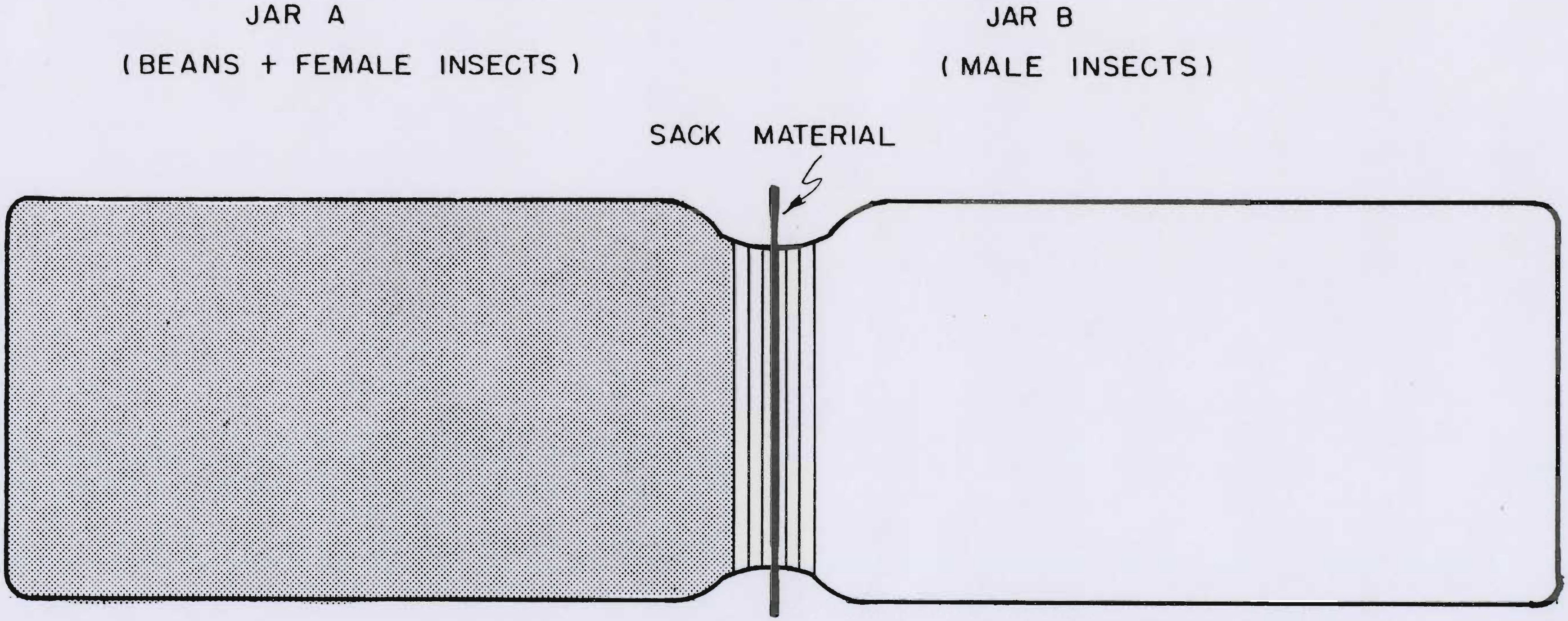


Figure 4.10. Experimental setup used in differential resistance to insect penetration study.

to eighteen. To each one of the first nine jars, twenty female Acanthoscelides obtectus specimens were added. To the other nine jars, twenty female Zabrotes subfasciatus specimens were added. The females were mixed with the beans to attract the males which were to be placed at the other side of the cover material. All insects were about 7 days old and were provided by the project's satellite laboratory at I.S.A.R. The open mouths of jars #1-3 and 10-12 were covered with jute fiber fabric; jars #4-6 and 13-15 were covered with black polyethylene sheeting; and jars #7-9 and 16-18 with a woven plastic fabric. The jute and woven plastic materials were cut from regular bags used by OPROVIA/GRENARWA. The polyethylene plastic sheeting was cut from the same type of bags used in the Large Scale Bagged Storage Study. To each jar a second jar was attached containing a number of male insects of the matching species. It was originally intended to place 20 insects in each one. However, some problems with mortality forced a reduction to a lower number. Table 4.12 shows the number of insects placed in each jar. The jars containing the Acanthoscelides species were kept on a bench in the laboratory, while the ones containing the Zabrotes species were placed in an incubator at 30°C to provide a more favorable environment. Then, starting two days after the insects were placed in the jars, the males present in the empty jar were counted on a daily basis for the next eight days. Because some of the insects may move back and forth through the material, the lowest count recorded for each jar was taken as a measure of permeability.

4.5.2. Results and Discussion

The results are shown in Table 4.12. The values listed are the minimum number of insects that were counted in the 'empty' jar. It can be seen that neither insect species was able to penetrate (chew through) the polyethylene plastic sheeting. All insects remained in the empty jar and no holes were observed in the plastic. The Zabrotes insects were also unable to pass through the woven plastic material. Only 3.3% of the Acanthoscelides specimens penetrated the plastic fiber material. On the other hand, 40% of the Acanthoscelides and 65% of the Zabrotes specimens got through the jute fiber material.

It can be concluded from these results that the plastic woven bags are superior to jute bags with respect to their insect penetration resistance. They form an efficient physical barrier to insects. Therefore, woven plastic bags may be effective in containing outbreaks of localized insect infestations.

4.6. Evaluation of Ambient Air Drying and Aeration in Bulk Storage

It appears that drying will be necessary for beans destined for long-term storage. Results from cookability studies indicate that decreasing moisture content to 11-12% w.b. significantly reduces development of the hard-to-cook problem. Because petroleum based fuels, required for heated air drying, are expensive in Rwanda while electrical energy is relatively inexpensive, ambient air

Table 4.12. Differential penetration resistance of woven jute fabric, plastic polyethylene sheeting and woven polyethylene fabric to *Acantoscelides obtectus* and *Zabrotes subfasciatus*.

Cover Material	Jar#	No. of male insects in Jar B		% Insects Passing
		Initial	Final	
Acanthoscelides obtectus				
Woven	1	20	12	40.0
Jute	2	20	12	40.0
	3	20	12	40.0
				40.0
Plastic	4	20	20	0.0
Sheet	5	20	20	0.0
	6	20	20	0.0
				0.0
Woven	7	20	20	0.0
Plastic	8	20	18	10.0
	9	9	9	0.0
				3.3
Zabrotes subfasciatus				
Woven	10	20	7	65.0
Jute	11	20	6	70.0
	12	20	8	60.0
				65.0
Plastic	13	13	13	0.0
Sheet	14	14	14	0.0
	15	13	13	0.0
				0.0
Woven	16	13	13	0.0
Plastic	17	13	13	0.0
	18	13	13	0.0
				0.0

drying is attractive. It relies on drying capacity in the ambient air and electrical energy to power drying fans.

Also, bulk storage of grain with aeration may be a useful alternative at the warehouse level in the future. Although beans and sorghum are currently stored in sacks at the warehouse level, potential inclusion of drying and cleaning operations as well as increased flexibility for storage and handling may provide impetus for bulk storage. Although aeration was not effective in the bag storage experiment, it is a useful and often necessary aid in management of bulk storage, particularly for large quantitites (>100 MT). Aeration helps to maintain uniform temperatures throughout the bulk and helps to equalize areas of non-uniform moisture content.

4.6.1. Methodology

Experiments were planned to evaluate ambient air drying and aeration in bulk storage. Plans were developed for 3 cylindrical steel bins. One bin has a nominal capacity of 20 metric tons and is 380 cm in diameter with a depth to the eave of 260 cm. The other two bins have nominal capacities of 10 metric tons each and are 280 cm in diameter with depths to the eave of 260 cm.

Two identical drying fans are available so that drying tests can be run with the large bin and one of the smaller bins at the same time. The drying fans (Dayton, model 3C073) are connected with a variable speed belt drive to a single phase electric motor (1 1/2 HP, 220 V, 11.5 A, 50 Hz). Smaller fans are also available to provide lower airflow rates for aeration studies.

The plans were developed and the project was put out for bids in August 1986. Drying tests were scheduled to start in November-December. However, delays in construction of the bins have postponed the start of drying tests until March 1987. Although this schedule more closely fits the period of the year in which ambient air drying of beans would be undertaken in Rwanda, it precludes the inclusion of any of the results in this report. However, the basic concept for applying ambient air drying in Rwanda will be discussed including some of the design data for the experiment.

4.6.2. Concepts for Ambient Air Drying

The major harvest for beans is December-January. Beans would normally start to be received in the market channels in February-March. Because of the availability of beans during this period, it would be logical to purchase and receive beans for long-term storage at this time. Relative humidities of the air are high at this point and therefore moisture contents of the beans are relatively high. This is illustrated by the weather data of Table 4.13. Monthly average temperature and relative humidity data for Karama for a representative year are indicated for 6, 12 and 24 hour periods. The corresponding equilibrium moisture contents for the

Table 4.13. Temperature, relative humidity and equilibrium moisture content (EMC) data for KARAMA for a representative year.

	12 hr(600-1800)		(EMC (%)		12 hr(900-2100)		EMC (%)	
Month	Temp. (°C)	RH (%)	Beans	Sorghum	Temp. (°C)	RH (%)	Beans	Sorghum
J	22.1	68	14.3	13.9	22.5	66	13.8	13.6
F	21.5	69	14.5	14.1	22.3	66	13.8	13.6
M	21.3	73	15.3	14.6	22.0	70	14.7	14.2
A	22.0	74	15.5	14.8	22.3	73	15.3	14.6
M	21.5	69	14.5	14.1	22.9	68	14.1	13.9
J	22.3	55	11.8	12.3	23.3	52	11.3	12.7
J	21.4	54	11.7	12.2	23.1	51	11.2	11.8
A	23.6	48	10.6	11.4	24.4	45	10.0	11.0
S	21.9	65	13.6	13.5	22.3	64	13.4	13.4
O	21.7	69	14.5	14.1	21.9	68	14.2	13.9
N	21.7	70	14.6	14.2	21.9	69	14.4	14.1
D	21.8	71	14.8	14.3	22.1	70	14.6	14.2

	6 hr(1100-1700)		(EMC (%)		24 hr(600-600)		EMC (%)	
Month	Temp. (°C)	RH (%)	Beans	Sorghum	Temp. (°C)	RH (%)	Beans	Sorghum
J	24.5	58	12.2	12.6	19.6	75	15.8	15.0
F	24.9	59	12.4	12.7	19.5	76	16.1	15.1
M	23.4	65	13.5	13.5	19.5	79	16.8	15.6
A	24.0	65	13.5	13.5	19.9	82	17.6	16.1
M	24.8	60	12.6	12.8	19.3	78	16.6	15.5
J	25.3	43	9.7	10.7	19.6	66	14.0	13.7
J	25.1	43	9.7	10.8	19.3	64	13.6	13.5
A	26.3	37	8.7	10.0	21.1	58	12.5	12.7
S	23.9	56	12.0	12.3	19.9	75	15.9	15.0
O	23.5	61	12.8	12.9	19.8	78	16.8	15.4
N	23.3	63	13.2	13.2	19.5	78	16.8	15.5
D	24.0	61	12.8	13.0	19.6	79	16.9	15.6

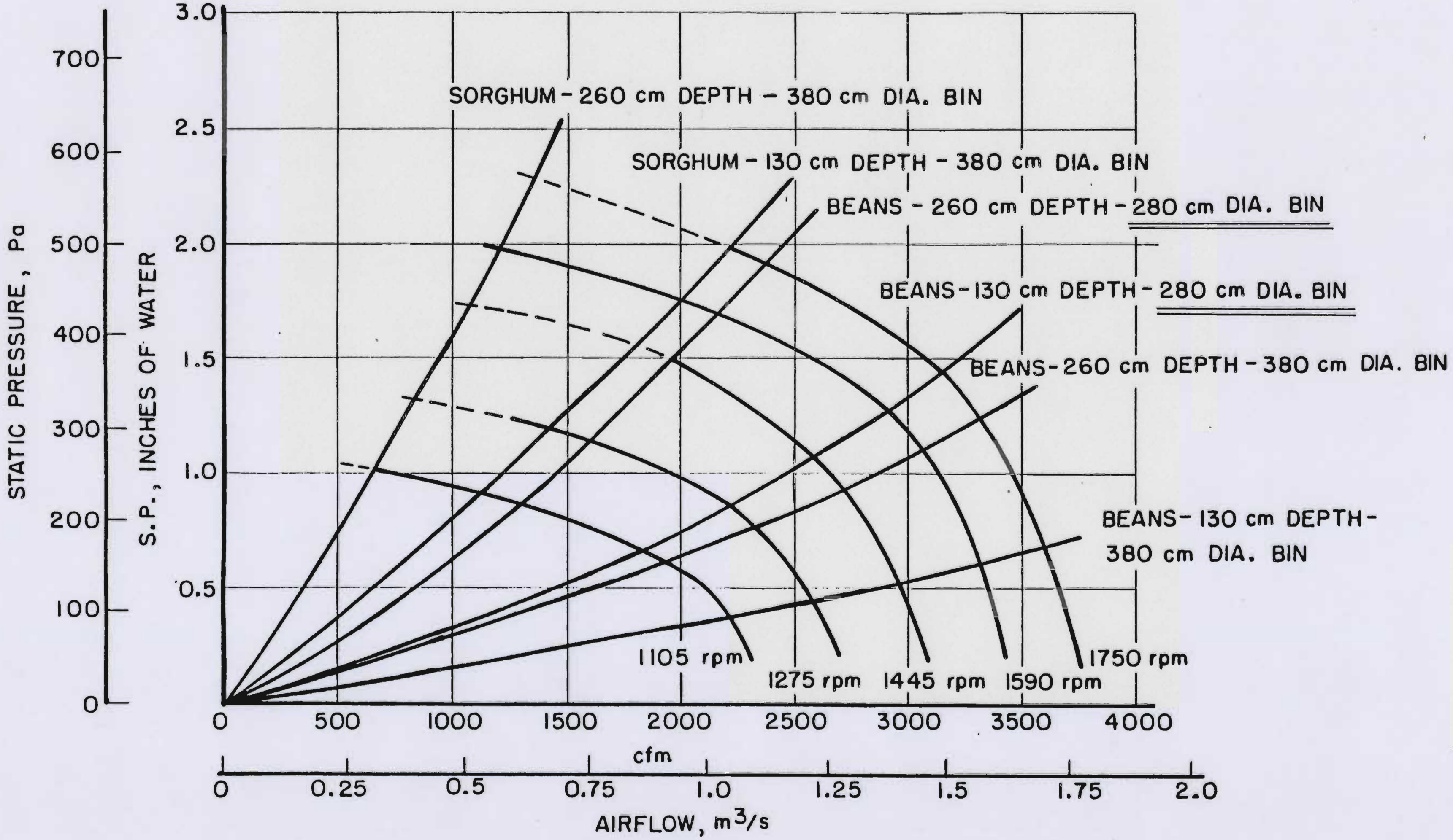


Figure 4.11. Airflow-static pressure curve for the large fan (Dayton, model 3C073) on the 380 cm and 280 cm diameter bins at several depths of fill for beans and sorghum.

temperature and relative humidity conditions for beans and sorghum are indicated. They show that on a 24 hour basis bean moistures in February to April approach 16-18% when in equilibrium with the ambient air. However by July-August they would approach 12-14%.

These data suggest that a procedure which runs the drying fan for 12 hours per day (900-2100 hrs) would result in beans reaching 14-15% moisture content during the February to April period. If operated at a warehouse receiving point, this procedure could be used to dry beans that arrive at moisture contents above 15% to the 14-15% range to reduce spoilage potential and reduce the rate at which the hard-to-cook condition develops. Once the 14-15% range is reached, the system could be shut off and beans held until the June-July period when lower humidity conditions allow drying to the 11% moisture content range by operating the fan for 12 hours per day (900 to 2100 hours). This two-stage approach is recommended for testing with the ambient air drying bins.

Figure 4.11 shows the airflow that can be expected with drying fans operating on the 380 cm diameter and 280 cm diameter bins. This figure was developed using the performance data supplied by the manufacturer and static pressure data from Figure 5.1 in Brooker et al. (1974). Pea bean (navy bean) data were used for estimating static pressures for Rwandan beans. A packing factor of 1.2 was applied for both beans and sorghum.

The results in Figure 4.11 indicate that one drying fan can deliver at least 1.5 m^3/s airflow rate to the 380 cm bin when filled to a 260 cm depth with beans (20-22 metric tons). Calculations using 12 hr per day (900 to 2100 hours) operating conditions for the February to April period show that 1.5 m^3/s airflow could dry 20 to 22 metric tons of beans from 17% to 15% moisture content in approximately 14 days.

This system has a ratio of approximately 14 metric tons of beans per 1 m^3/s airflow rate. In designing future systems, it should be possible to increase this ratio to 30 to 50 metric tons of storage capacity per 1 m^3/s airflow rate since beans will likely be received over a period of time and because the allowable drying time could be extended 4 to 6 weeks without harm. Future experiments should test this recommendation.

4.7. Comments on Warehouse Design and Management

The warehouse design is adequate for storage of beans and sorghum in bags. The structures provide good protection from rain, runoff and drainage water. They provide only limited protection from rodents and birds. Ventilation is adequate although some improvements could be made to reduce heat gain and therefore interior temperatures during the day. Monitoring of stacks in the Kicukiro warehouse indicated higher average temperatures at the top of the stacks than at the bottom. The higher temperatures accelerate development of the hard-to-cook problem in beans undergoing long-term storage. Higher temperatures also provide a more favorable environment for insect growth.

Several techniques could be used alone or together to reduce temperatures in the warehouse. Although there is ample venting at the eaves, inclusion of a ridge vent in new construction could promote additional natural ventilation, cooling the area under the roof of the warehouse during periods of the day when solar heat load on the roof is greatest. Adding insulation on the underside of the roof would also help to reduce heat load on the interior of the warehouse. Combining a ridge vent with insulation should significantly reduce the heating of the warehouse due to solar load and reduce the average temperature of the interior.

Mechanical ventilation using a fan (or fans) powered by electric motors might be more easily adapted to an existing storage. Fans could be placed at the ridge either on top of the roof or in the ends of the building to exhaust air. Fans could be thermostatically controlled to reduce temperature in the upper areas of the warehouses during the day.

With careful use of insulation to reduce heat gain during the day in conjunction with mechanical ventilation to draw in cool air during the night, it should be possible to maintain daily average temperatures in the warehouse which are less than daily ambient temperatures. This should be considered for warehouses used for long-term storage of beans.

The warehouses are also used for receiving beans and sorghum. Significant amounts of space are required for emptying bags as received, mixing insecticide and rebagging. Including these operations in the same structure where bag storage occurs detracts from the quality of the storage environment. The dust and loose beans or sorghum created by the receiving and bagging operations make it difficult to maintain an optimum storage environment.

The current receiving and bagging operations have limitations as outlined by Cloud (1984) and Thompson (1985). If attempts are to be made to improve service to customers delivering beans and grain along with efforts to improve quality of product received and put into storage, improved handling and cleaning procedures, and equipment will be needed. In addition some provision for drying should be included at locations where beans are being prepared to go into long-term (greater than 1 year) storage.

Specific recommendations are not possible, but some general ideas can be presented for handling at a storage facility. If beans or sorghum are sampled and some form of quality analysis is performed as grain is received, opportunity exists for segregating individual lots of grain by moisture content and/or damage level. Potential variability of moisture content of beans received is illustrated in Fig. 4.12. This figure is based on 189 observations of beans purchased by GRENARWA at Kicukiro on April 15, 1986. Beans

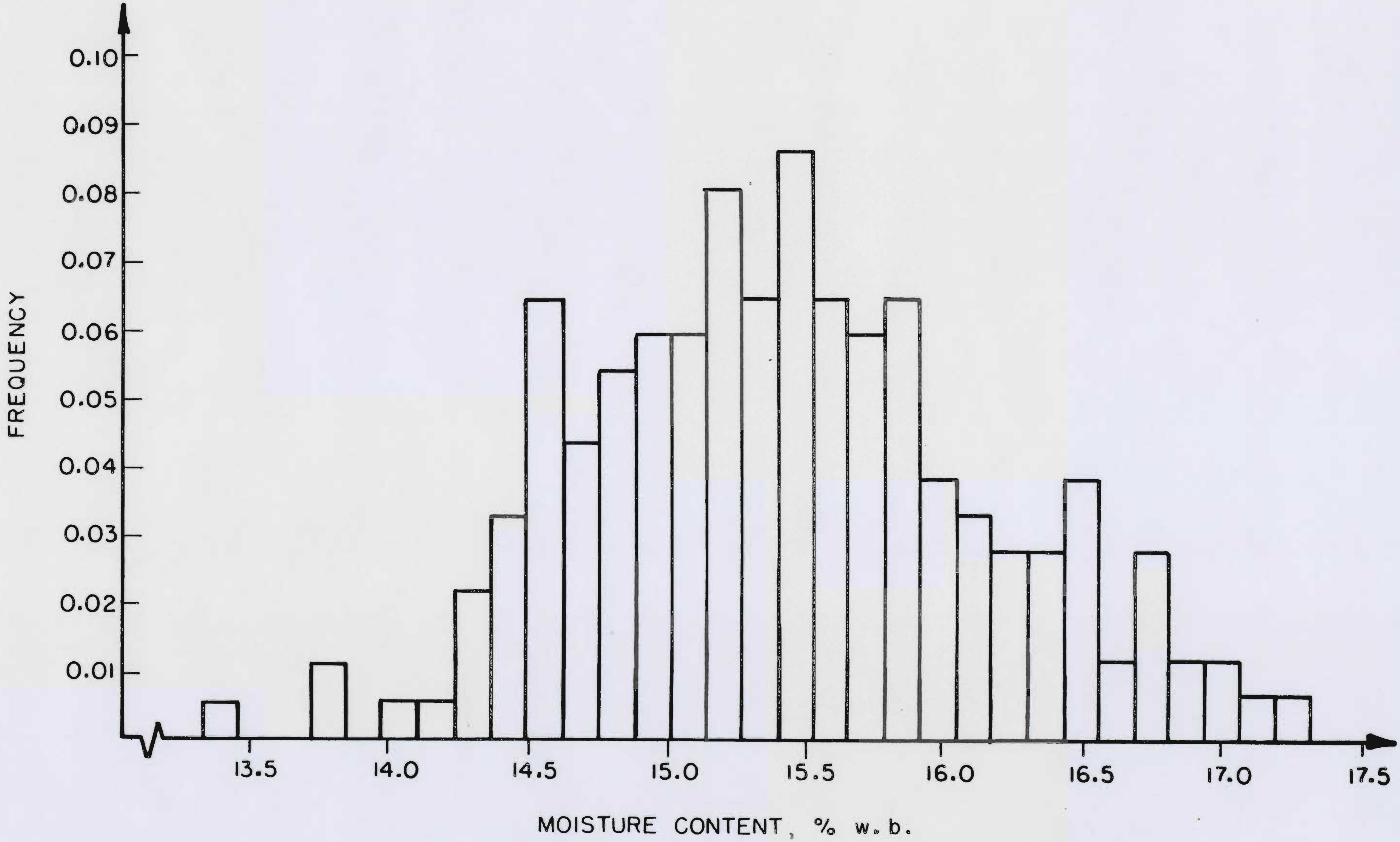


Figure 4.12. Frequency distribution of the moisture content of beans purchased by GRENARWA from producers (April 15, 1986--189 observations).

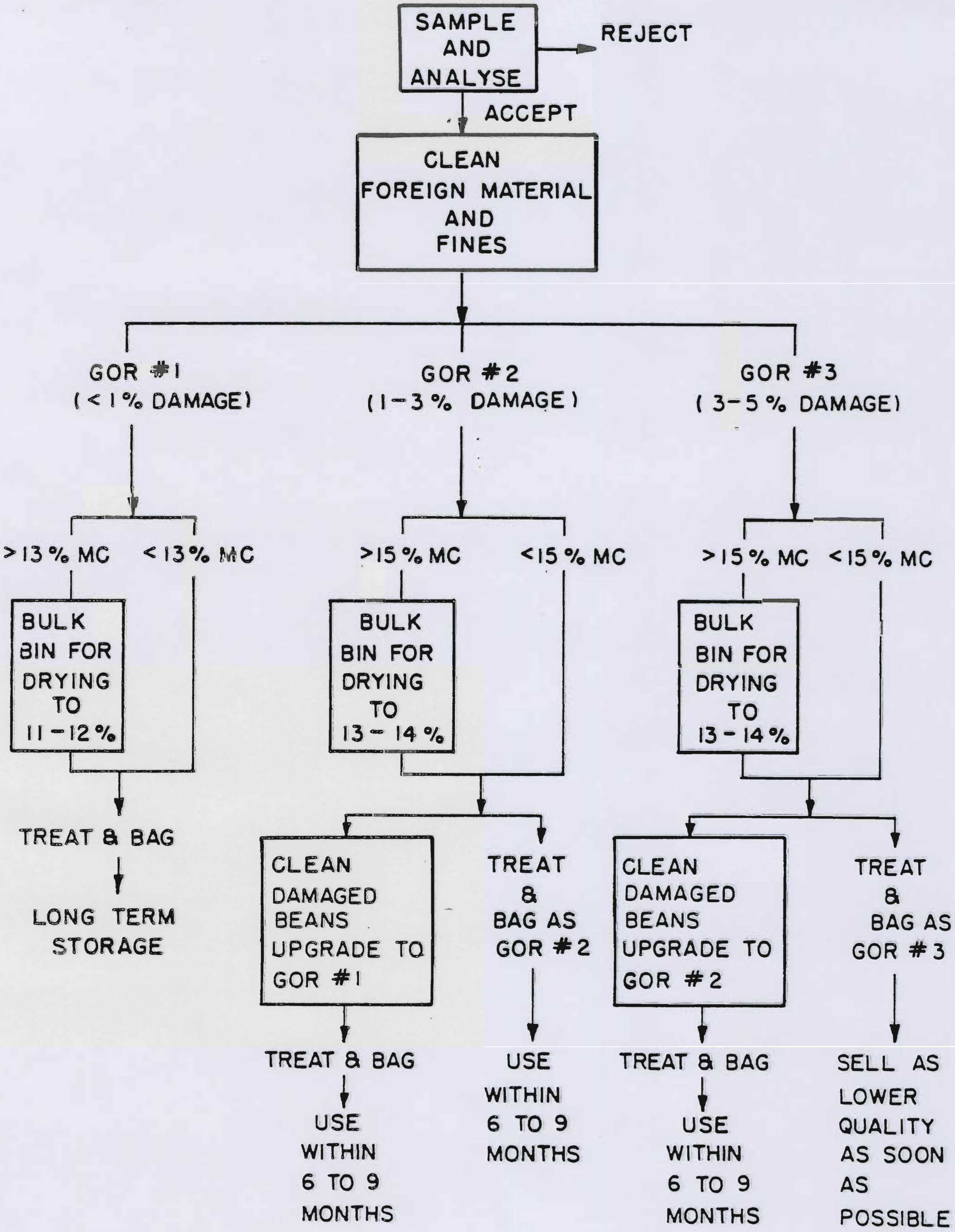


Figure 4.13. Schematic diagram of a procedure for separating beans by moisture content and quality.

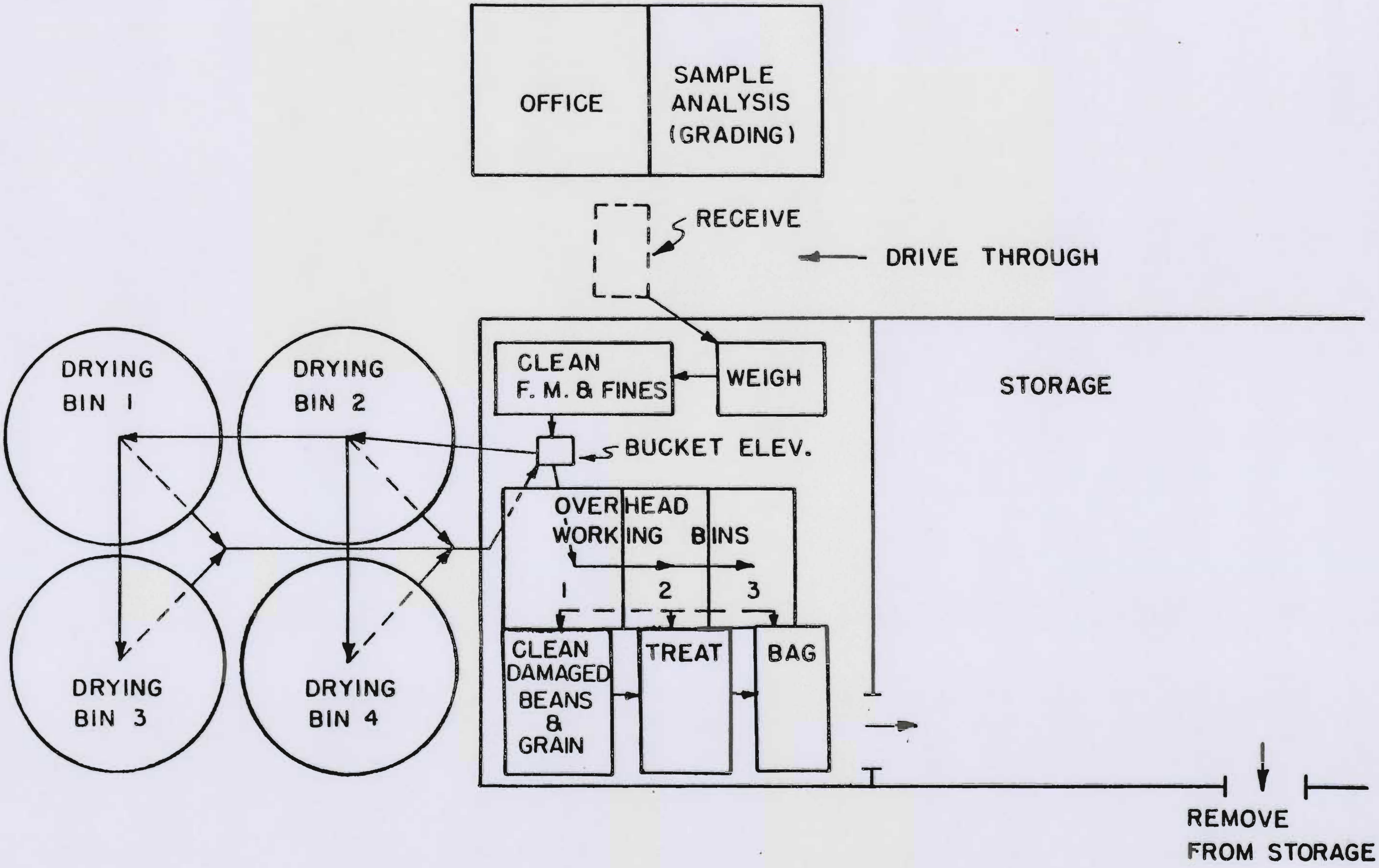


Figure 4.14. Diagram (not to scale) of a receiving, drying, cleaning, treating, bagging and storage facility.

requiring drying (e.g.,. > 15% moisture content) could be separated at receipt and sent to a drying bin.

Fig. 4.13 is a diagram of a potential procedure to sample, analyze, accept or reject, clean and segregate beans by moisture content and damage as they are received. The figure shows a wide range of groupings that could be made as beans are received. In a particular application only a few of these segregations might be made. The choice would be related to the functions of the particular receiving facility.

If procedures involving receiving, cleaning, segregation, drying, treating and bagging are to be effectively undertaken at a warehouse facility, provisions for handling and processing (cleaning, treating, bagging) are necessary. Fig. 4.14 is a diagram (not to scale) of a drying, handling and storage facility. It is a facility capable of receiving 4000-5000 metric tons (MT) per year. It has four 300 MT drying/bulk storage bins. If the four bins were used for ambient air drying of beans, they would be capable of drying 1200 MT of beans per season for long-term storage. These bins would have 10 meter diameters and 5 meter bean depths and would be equipped with 10 kW (ca 14 hp) fans. Under these conditions an airflow of 10 m^3/s at a static pressure of 500 Pa would be expected.

Beans would be sampled and analyzed as they were received. Beans would be handled in bulk through the drying, cleaning and treating operations. After drying, cleaning and treating, they would be bagged and sent to storage. Materials handling equipment including belt conveyors and a bucket elevator would transfer beans through the various steps until they are bagged.

The drying, cleaning and treating operations could be scaled to various sizes of receiving facilities. Provisions for drying would be needed only at facilities which are preparing beans for long-term storage.

4.8. Summary and Conclusions

Obtaining uniform temperatures in aerated bag piles proved to be difficult because of nonuniform airflow distribution. Obtaining uniform airflow distribution is difficult because of the low resistance to airflow provided by the stacks of bags. Methods to improve uniformity of airflow distribution in aerated bag piles were considered, but it was decided that it would be more productive to direct efforts at ways to reduce interior temperatures by reducing heat load on the warehouse and improving ventilation.

Temperature measurements in the non-aerated pile indicated temperature gradients in the pile. Temperatures were higher at the top of the pile than at the bottom. This is likely a result of heat load on the roof of the building during the daytime hours. An experiment to evaluate the potential effect of insulation on reducing roof temperatures was conducted. The results suggested that including a layer of insulation under the roof along with improved roof ventilation would significantly lower roof temperatures and, therefore, heat transfer to the warehouse interior during daytime hours when solar heat load is greatest. Lower interior temperatures can potentially reduce the rate of insect development and the rate at which beans become hard-to-cook.

The experiment involving monitoring of non-aerated and aerated bag piles showed that storage related damage was already high for beans going into storage. These results suggest that procedures to evaluate bean quality as beans are received with the option of segregating beans by various quality levels and of cleaning to improve quality should be considered. Adopting a system of quality standards would facilitate this effort.

Plans were developed for an ambient air drying experiment. Drying is potentially important for beans destined for long-term storage because the hard-to-cook problem develops more slowly at lower moisture contents. Ambient air drying fits well with the climatic conditions and energy resources of Rwanda.

Increased activities involving cleaning of beans and sorghum along with inclusion of drying in some operations will increase the need for improved handling operations at the warehouse. Bottlenecks in receiving, treating and rebagging already exist at the warehouse level. Thus future work should focus on solutions to handling problems.

Experiments involving 1) the effectiveness of aeration in bulk storage in retarding the development of insects, and 2) the resistance of different bag materials (jute, woven plastic and polyethylene plastic sheet) to insect penetration were started. These have provided a good opportunity for Rwandan staff to design and carry out experiments (Objective 5). The aeration experiment is still underway. The bag material experiment showed that woven plastic provided a more effective barrier to insect penetration than jute. These results are promising and should be explored further.

5. COOPERATIVE STORAGE LEVEL EXPERIMENTS

Based on the problems observed to exist at the cooperative level which are described in Chapter 2, it was decided to undertake the following activities:

a. evaluate the thermal behavior of grain bulks stored in cooperative silos.

b. evaluate the effect of aeration on lowering and equalizing the existing temperatures.

b. analyze the silo design for possible improvements, especially with regard to a more rapid handling and a more efficient monitoring of the stocks.

5.1. Aeration Experiment

5.1.1. Methodology

The first step consisted of selecting the experimental sites for the aeration experiments with beans. Because of the influence of altitude and/or temperature on the development of insects and fungi, it was decided to select one silo in each of the three altitude regions (low, medium and high) of the country. The main criteria for selecting sites were the altitude, the long-term availability (one year) of two compartments, the full-time presence of a manager and absence of known structural defects of the silo. After visiting a number of cooperatives that participated in the storage survey, the following three locations were selected (Fig. 2.1):

Rusumo (low altitude region) - 1400 m
Rusatira (medium altitude region) - 1750 m
Kanama (high altitude region) - 2000 m

Since it was felt necessary to include also some aeration and monitoring work with sorghum, one silo in the middle altitude region (Gikoro - 1750 m) was added to the program.

The installation of the equipment implied some physical modifications of the silo structure. Therefore a letter was sent to the executive boards of the four cooperatives explaining the scope and nature of the work and requesting written permission for its execution.

At each of the experimental sites, two compartments were monitored for changes in temperature distribution within the grain mass as well as changes in overall grain quality. One of the compartments received an aeration treatment, the other one served as a control. First a network of twenty five thermocouples was installed in each compartment. They were installed at five locations (near an outside corner, near an outside wall, in the center, near an inside wall and near an inside corner) and at five levels (at 0.25, 0.75, 1.25, 1.75 and 2.25 m from the floor). They were attached to ropes tied to eyebolts anchored in the floor and ceiling of the compartment. The numbered thermocouple wires (see Fig. 5.1) were bundled and extended far enough so that they could easily be reached through the man hole for temperature measurements.

The aeration system consisted of a fan connected to a circular metal pipe and a plenum chamber (Fig. 5.2). The fan was an axial propeller type fan powered by a 1/3 HP electric motor. In Rusatira, Rusumo and Gikoro the electrical power was provided with a portable generator. In Kanama line power was available. The connecting pipe was about 1.2 m long and had a diameter of 15 cm. To install the pipe a hole was cut at floor level in the center of the outside wall of the aerated compartment. Inside the compartment the pipe was connected to a plenum chamber (2.0 x 2.0 x 0.15 m) which formed a perforated floor centered on the compartment floor. A preliminary test in Rusumo showed that the surface area of the plenum chamber had to be this large in order to obtain an acceptable air distribution within the beans, because the resistance to air flow in beans is very low. The direction of the air flow was downward through the bean mass at Kanama, Rusatira and Rusumo and upward through the sorghum at Gikoro. The man hole in the compartment ceiling served as the air inlet. Cold air was sucked daily through the grain from midnight to 6:00 a.m. at a rate of about 2.65 m^3/min (96 CFM) and a static pressure of 10 mm (0.4") of water column.

GRENARWA provided the stocks in Kanama, Rusatira and Gikoro for this research. In Rusumo the stocks originally belonged to the cooperative but were purchased by GRENARWA towards the end of the experiment. As soon as the stocks were in place, a guard was hired to turn the aeration equipment on and off at the indicated times (except at Kanama where an electrical time clock was used). The silo managers were given a Cole-Parmer thermocouple thermometer and data sheets. Thermocouple readings were taken every working day of the week by the manager and recorded on the data sheets. At the same time records were kept of the daily minimum and maximum temperatures. Composite samples were drawn at regular time intervals from the bottom, middle and top layers in each compartment for a complete quality analysis.

5.1.2. Results and Discussion

5.1.2.1. Kanama

The silo in Kanama is located near the Gisenyi-Ruhengeri road, at 13 km from Gisenyi, in the foothills of the volcanic mountain range. Two compartments located side by side on the north side of the silo were selected for this experiment. Their outside wall facing north is exposed to rains from that direction. Just prior to the start of the experiment, it was observed that the inside surface of this wall showed several wet spots. Apparently the walls are not moisture impermeable. Before placing the beans

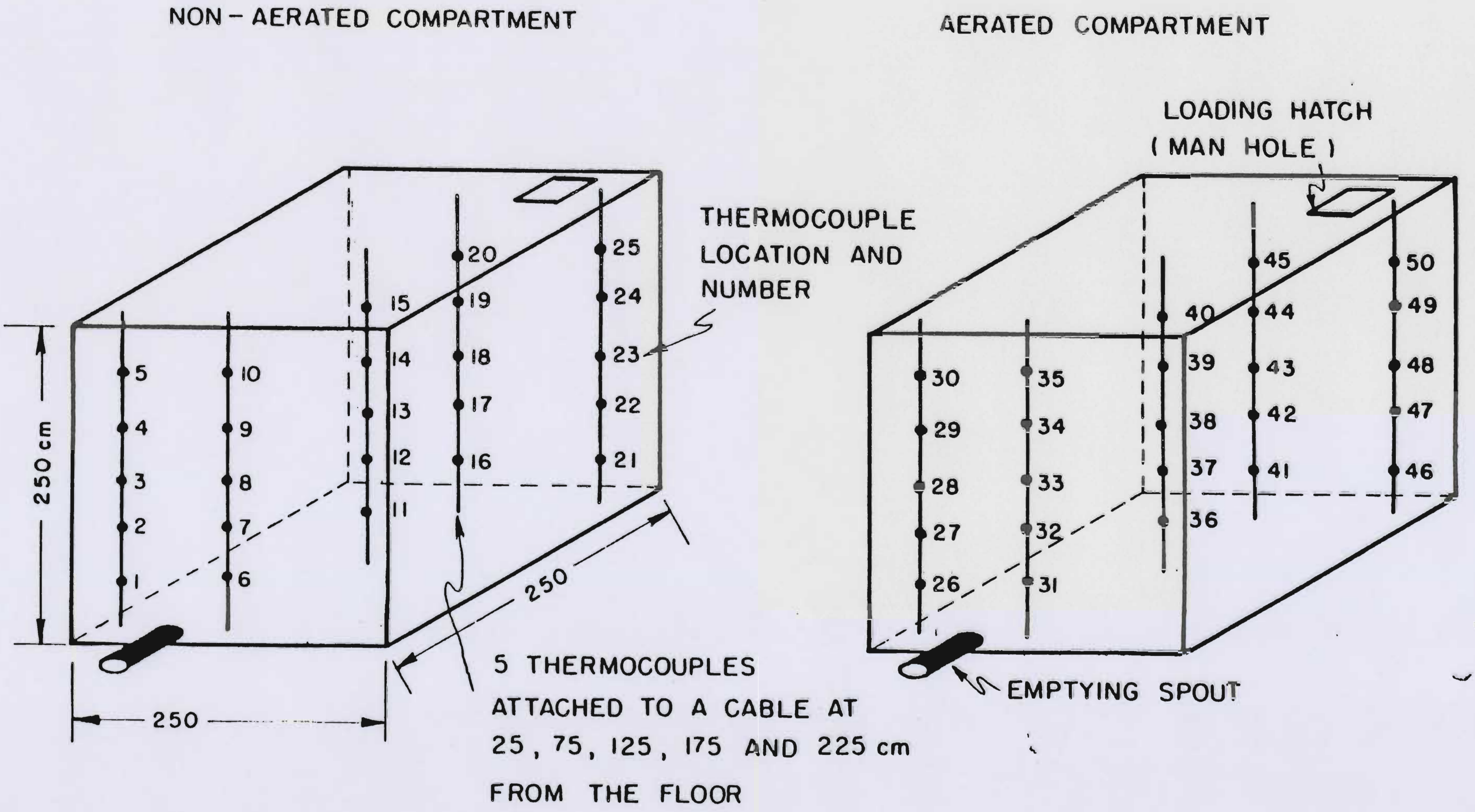


Figure 5.1. Thermocouple locations in the non-aerated and the aerated compartments at the cooperative silos of KANAMA, RUSATIRA, RUSUMO and GIKORO.

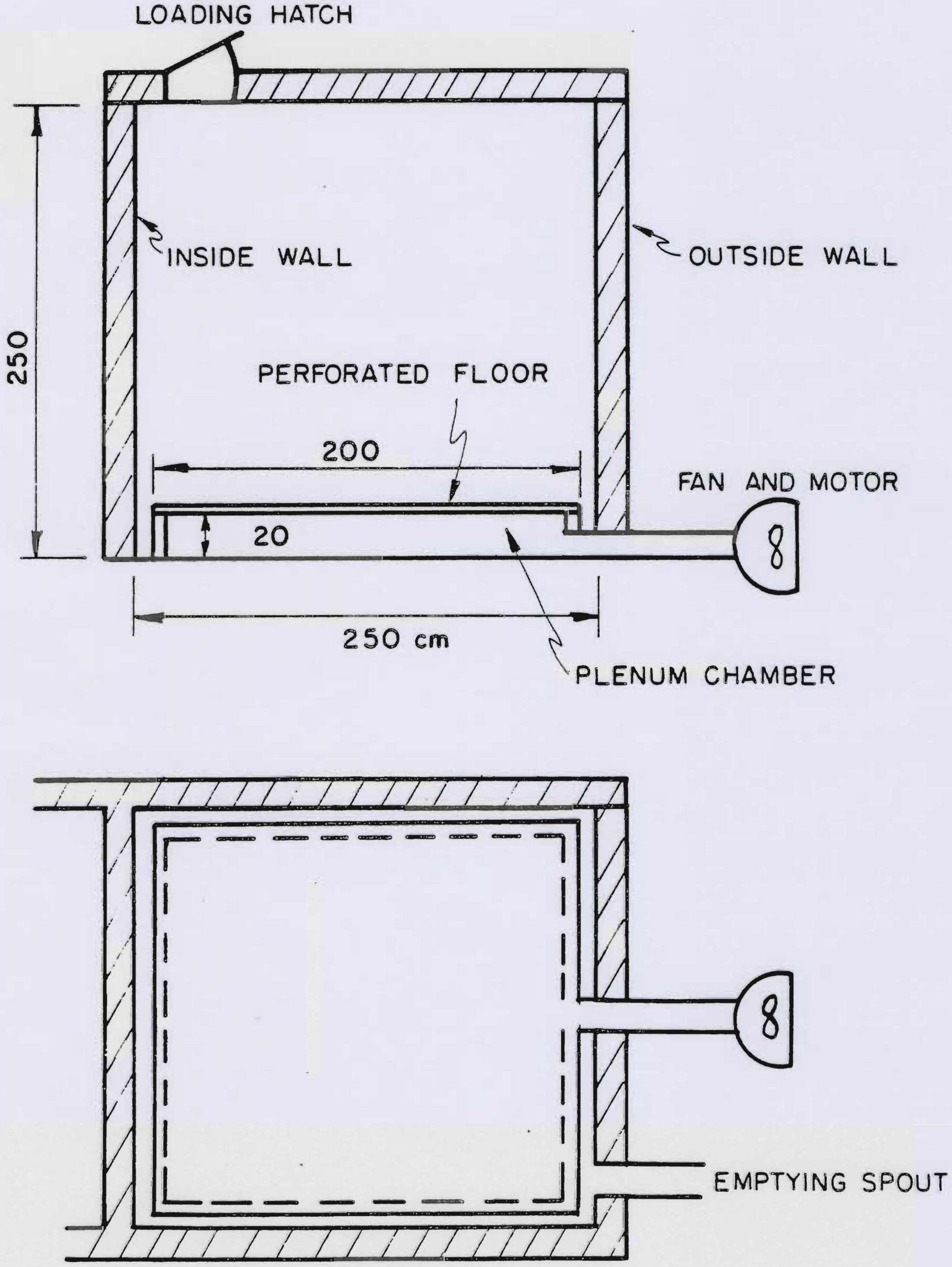


Figure 5.2. Diagram of aeration system in the cooperative silos at KANAMA, RUSATIRA, RUSOMO and GIKORO.

in the silo, the fan was run for four days to remove some of this moisture.

The aeration experiment in Kanama started on January 18, 1986 and ended on January 13, 1987. Samples were taken after 0.0, 3.5, 7.0, 9.0 and 12.0 months of storage. The beans had an average moisture content of 15.7% w.b. at the beginning of the experiment and had been harvested during the months of October and November of 1985. Both compartments were fumigated on January 30, 1986.

The average ambient minimum and maximum temperatures (Table 5.1) during the time of this experiment were 14.2 and 23.8°C, respectively. Table 5.2 shows the ten-day temperature distributions measured in the non-aerated compartment (NAC). The average temperatures ranged from 23.3°C in the center (T14) to 18.4°C (T25) near the man hole. The top layer was about 1°C colder than the bottom layer. The temperature distribution in the aerated compartment (AC) (Table 5.3) was dominated by a vertical temperature gradient with the coldest temperature near the top of the bulk. This was to be expected since the cold air enters the compartment through the man hole and first passes through the top layer. The average temperatures were 15.0°C (T40) at the center top and 19.4°C (T26) at the bottom of the compartment near the emptying spout. The overall average temperature in the NAC was 20.2°C and 17.1°C in the AC. The temperature reduction obtained by applying aeration was thus about 3°C. The average ambient temperature was 19.0°C, which is only 1.2°C lower than the average temperature within the NAC. These data indicate a low level of biological activity within the bean mass.

The moisture content (MC) in the AC cycled through a drying and rewetting period, while the MC in the NAC hardly changed (Table 5.4). The first 3.5 months of the storage period coincided with the January-April rainy season. During this period a rewetting of the top layer took place in the AC while the two lower layers dried somewhat. Between 3.5 and 9.0 months in storage (dry season from April to September) the beans were further dried by 1.7% on average from their original MC. This trend reversed during the last three months coinciding with the October-December rainy season. The test weight and the percent foreign material remained relatively constant throughout the storage period.

The total number of insects (live and dead) per kg of grain did not change significantly in either one of the compartments (Table 5.5). The fumigation treatment at the beginning was effective in controlling the development of bruchids. Although large numbers of live insects were found in the first samples, none were found in any of the subsequent samples. Also the percent insect damaged beans remained stable throughout the storage period and incubation tests never yielded any live insects. The colder climate in this high altitude region probably contributes to this favorable situation.

Table 5.1. Ten-day minimum and maximum ambient temperatures (°C) recorded at the cooperative silos in RUSUMO, RUSATIRA, KANAMA and GIKORO (January-December, 1986).

(I, II, III = first, second and third 10-day period, respectively)

		RUSUMO		RUSATIRA		KANAMA		GIKORO	
Month	Decade	Min	Max	Min	Max	Min	Max	Min	Max
January	I	0.0	0.0	0.0	0.0	14.0	24.5	17.0	24.8
	II	-	-	-	-	14.5	24.8	18.1	26.0
	III	-	-	-	-	14.2	22.4	17.5	26.1
February	I	-	-	-	-	14.6	23.1	17.1	24.0
	II	-	-	-	-	13.2	24.0	16.3	24.3
	III	-	-	-	-	13.7	24.2	17.1	25.7
March	I	-	-	-	-	13.7	23.1	16.8	24.4
	II	-	-	18.5	26.6	13.6	23.9	16.3	23.8
	III	-	-	18.1	27.7	13.1	24.2	17.7	25.6
April	I	18.1	25.7	18.2	26.4	14.8	23.7	17.2	24.0
	II	17.2	27.1	18.1	27.4	16.2	25.1	17.9	25.4
	III	18.0	27.7	17.8	26.8	15.4	22.9	17.9	24.0
May	I	18.5	27.8	18.5	27.1	14.6	24.0	17.8	24.5
	II	16.8	27.7	18.4	27.9	15.3	24.3	17.7	24.3
	III	16.6	27.4	18.0	26.8	14.8	24.2	17.2	22.9
June	I	15.7	27.6	18.0	28.1	13.0	23.3	16.7	23.8
	II	15.4	27.1	17.8	27.5	13.5	22.4	17.0	24.4
	III	15.0	27.7	-	-	13.9	23.1	17.7	24.3
July	I	13.8	28.3	18.0	27.1	12.8	23.2	17.4	24.8
	II	14.1	28.9	18.3	27.9	12.6	23.0	18.0	25.3
	III	14.2	28.2	16.3	28.0	17.2	22.9	17.5	24.7
August	I	-	-	18.0	28.0	13.0	25.2	18.0	25.6
	II	-	-	17.9	27.9	11.4	25.4	19.0	27.0
	III	-	-	18.0	28.1	13.9	27.0	20.0	27.8
September	I	17.3	30.7	18.3	28.3	15.0	23.9	18.8	27.3
	II	16.9	30.7	18.3	28.0	14.7	23.6	17.3	26.0
	III	16.0	31.0	-	-	14.0	25.4	17.0	27.4
October	I	16.0	31.4	18.5	30.0	-	-	-	-
	II	15.1	30.2	18.5	28.3	-	-	-	-
	III	16.0	30.8	18.4	28.9	-	-	-	-
November	I	17.7	26.9	18.7	29.2	-	-	-	-
	II	16.8	27.3	17.0	29.0	-	-	-	-
	III								
December	I	-	-	17.9	28.7	16.0	21.9	-	-
	II	-	-	17.8	27.1	13.0	22.3	-	-
	III	-	-	17.3	28.4	15.9	24.0	-	-
Mean		16.3	28.5	18.0	27.9	14.2	23.8	17.6	25.1

Table 5.2. Ten-day mean temperatures (°C) in the non-aerated compartment of beans at the cooperative silo at KANAMA (January 1986-January 1987). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	AVE
January	II	--	21.7	21.7	22.3	20.7	22.0	22.3	22.7	23.0	21.0	21.3	23.0	23.7	26.3	22.3	20.3	22.0	21.0	23.0	21.0	20.0	21.0	21.7	20.7	20.3	21.9
	III	20.0	20.0	20.9	21.1	19.1	21.4	22.1	22.6	22.1	19.5	21.0	24.1	24.9	29.5	25.4	20.0	22.0	22.1	23.0	20.1	19.5	20.0	20.3	19.3	18.5	21.5
February	II	18.9	19.1	19.5	19.3	18.8	19.9	20.5	20.9	20.9	19.0	20.0	22.5	24.4	25.6	24.8	19.8	20.8	21.5	21.5	20.0	19.6	20.0	20.0	19.5	18.9	20.6
	III	19.5	19.5	19.5	19.5	18.8	19.5	20.0	20.5	20.3	19.2	20.0	22.0	23.5	24.3	23.3	19.0	20.0	20.5	20.3	19.5	19.0	19.5	19.7	19.0	18.0	20.2
March	I	18.9	18.9	19.0	19.0	18.0	19.3	20.0	20.0	20.0	18.0	20.0	21.6	22.9	23.6	22.3	18.9	19.0	19.4	19.3	18.4	19.0	19.0	18.9	18.3	18.0	19.6
	II	19.3	19.3	19.3	19.2	18.3	19.6	20.0	20.0	20.0	18.2	19.9	21.2	22.3	22.9	21.3	18.6	18.9	19.0	18.8	18.0	19.0	19.0	19.0	18.3	18.0	19.5
	III	19.6	19.6	19.6	19.4	18.8	19.4	19.6	20.1	19.8	18.6	19.3	21.0	22.3	22.0	20.4	18.0	18.1	19.0	18.4	18.0	18.4	18.0	18.3	18.0	17.6	19.3
April	I	20.4	20.3	20.3	20.0	19.3	20.0	20.0	20.1	20.0	19.0	20.0	20.9	21.6	22.0	20.1	18.7	18.7	19.0	18.9	18.4	18.6	18.6	18.9	18.6	18.3	19.6
	II	20.8	20.4	20.3	20.1	19.9	20.0	20.4	20.4	20.0	19.0	20.0	20.5	22.0	22.0	20.1	19.0	19.0	19.1	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.8
	III	20.2	20.2	20.1	20.1	19.6	20.0	20.0	20.1	20.0	19.0	20.0	20.6	21.3	21.3	20.0	19.2	19.2	19.8	19.0	19.1	19.0	18.8	19.0	18.9	18.3	19.7
May	I	21.6	21.4	21.3	21.3	20.3	20.1	20.4	20.6	20.1	19.4	20.0	21.0	21.7	21.9	20.3	19.6	19.7	20.0	19.0	19.0	19.1	19.1	19.1	19.3	19.3	20.2
	II	21.3	21.0	21.0	21.0	20.0	20.3	20.4	20.4	20.1	19.0	20.1	21.0	21.9	21.9	20.3	20.0	20.0	20.0	19.9	19.1	19.0	19.0	19.0	19.0	18.9	20.1
	III	20.9	20.9	20.9	20.9	19.9	20.0	20.3	20.6	20.0	19.0	20.4	21.1	22.1	22.0	20.0	20.0	20.0	18.9	18.7	18.9	19.0	18.8	19.0	18.9	18.3	20.0
June	I	20.4	20.4	20.4	20.4	19.3	20.1	20.1	20.4	20.1	18.4	20.4	21.1	22.0	22.0	20.0	19.7	19.7	19.6	18.9	18.0	19.0	18.3	18.1	18.1	18.0	19.7
	II	21.1	21.1	21.1	21.0	19.8	20.1	20.1	20.4	20.0	18.8	20.6	21.7	22.0	22.0	20.0	19.7	19.0	19.0	18.6	18.0	19.0	17.6	18.0	18.0	17.9	19.8
	III	21.9	21.6	21.6	21.4	20.4	20.9	20.9	21.0	20.6	19.4	21.0	21.9	22.0	22.0	20.5	20.0	19.0	19.1	18.3	18.6	19.0	18.8	18.6	18.8	18.6	20.2
July	I	21.5	21.5	21.5	21.0	19.7	20.0	20.0	20.0	20.0	18.3	21.0	21.8	22.0	22.0	20.0	20.0	19.0	19.0	18.2	18.0	19.0	17.5	18.0	18.0	17.3	19.8
	II	22.0	22.0	22.0	22.0	20.1	20.3	20.6	20.9	20.0	19.0	21.0	22.0	22.0	22.0	20.4	19.5	19.0	18.9	18.1	18.0	18.9	18.0	18.0	18.0	18.0	20.0
	III	21.6	21.2	20.9	20.9	19.4	20.0	20.0	20.1	20.0	18.1	21.0	22.0	22.0	22.0	20.0	19.0	18.7	18.4	18.0	17.1	18.1	17.6	17.7	17.2	17.0	19.5
August	I	21.3	21.2	21.0	20.8	19.8	20.2	20.2	20.3	20.0	18.7	20.3	22.0	22.2	22.7	21.0	19.0	18.0	18.0	18.2	18.0	18.0	17.2	17.7	17.5	17.7	19.6
	II	22.0	22.0	21.9	21.8	20.4	20.9	20.9	21.1	20.8	19.5	20.1	21.6	22.0	22.4	21.0	19.0	18.0	18.0	17.6	18.0	18.1	17.6	18.1	18.1	18.1	20.0
	III	23.7	23.7	23.7	23.4	22.4	21.7	21.8	22.4	22.0	21.1	21.0	22.0	22.6	23.0	22.0	19.3	18.8	18.7	18.7	19.6	19.0	18.4	19.2	19.7	19.7	21.1
September	I	21.8	21.9	22.0	22.0	20.8	21.1	21.8	21.9	21.9	20.0	21.0	22.0	22.9	23.0	21.8	20.0	19.0	19.3	19.4	19.3	19.3	17.1	19.0	19.3	19.0	20.7
	II	21.2	21.2	21.6	21.8	20.2	20.9	21.2	21.8	21.8	19.9	21.0	22.0	23.0	23.7	21.9	19.9	19.6	19.9	19.6	19.0	19.9	17.4	19.1	18.9	18.7	20.6
	III	21.1	21.4	21.7	21.7	20.7	20.7	21.3	21.7	21.7	19.9	21.0	22.1	23.4	24.0	22.4	20.0	20.0	20.0	20.0	19.6	20.0	18.9	19.1	18.9	18.7	20.8
October	I	21.2	21.4	21.7	21.8	20.7	21.0	21.1	22.0	22.0	20.0	21.1	22.4	23.8	24.0	23.0	20.0	20.0	20.0	20.0	20.0	20.0	19.2	19.8	19.4	19.3	21.0
	II	20.8	20.8	20.9	20.9	20.1	20.8	21.0	21.5	21.9	20.0	21.4	22.8	23.9	24.3	23.0	20.0	20.0	20.4	20.1	19.9	20.4	19.6	20.0	19.8	19.1	20.9
	III	20.6	20.6	20.7	20.7	19.8	20.6	21.1	21.7	21.7	19.8	21.4	23.0	24.0	24.4	23.0	20.0	20.0	20.8	19.6	19.8	20.2	20.2	19.8	19.4	18.9	20.9
November	I	21.3	21.2	21.0	20.8	19.8	20.2	20.2	20.3	20.0	18.7	20.3	22.0	22.2	22.7	21.0	19.0	18.0	18.0	18.2	18.0	18.0	17.2	17.7	17.5	17.7	19.6
	II	20.0	20.3	20.6	20.4	19.3	20.1	20.3	21.0	21.0	19.2	20.7	22.7	23.3	23.6	22.6	19.7	19.4	19.4	19.3	18.8	19.3	19.1	18.7	18.2	18.0	20.2
	III	19.4	19.6	20.0	20.0	19.0	19.0	20.3	21.0	21.0	19.5	21.0	22.8	23.9	24.4	23.8	19.9	19.9	20.1	19.9	19.0	20.0	19.6	19.0	18.8	18.3	20.4
December	I	19.1	19.6	19.9	19.9	19.0	20.0	20.3	21.0	21.0	19.1	20.9	22.2	23.7	24.2	23.4	19.7	20.0	20.4	20.1	19.4	19.3	17.0	19.0	18.9	18.1	20.2
	II	18.2	18.6	18.6	18.6	17.7	19.0	19.9	20.1	20.1	18.3	20.3	22.1	23.1	24.0	23.0	19.7	19.7	20.6	19.0	19.2	18.8	18.1	18.4	18.0	17.6	19.6
	III	18.9	19.0	19.4	19.4	19.0	19.4	19.9	20.3	20.3	19.3	19.9	21.6	22.9	23.8	23.3	20.6	20.0	20.6	20.3	19.4	19.0	18.8	19.0	18.4	18.4	20.0
January	I	18.1	18.3	19.0	19.0	18.1	19.1	19.6	20.1	20.1	18.5	20.0	21.9	22.9	24.0	23.0	19.0	20.0	20.0	19.4	19.1	18.8	17.0	18.4	18.1	17.9	19.6
	II	18.0	18.0	18.5	18.5	17.5	18.5	19.0	19.5	19.5	18.0	20.0	21.5	22.5	23.5	23.0	19.0	19.5	20.0	17.5	18.5	18.5	18.0	18.0	18.0	17.5	19.2
Average		20.5	20.5	20.6	20.6	19.6	20.2	20.5	20.8	20.7	19.2	20.5	21.9	22.7	23.3	21.8	19.5	19.5	19.7	19.3	18.9	19.1	18.6	18.9	18.7	18.4	20.2

Table 5.3. Ten-day mean temperatures (°C) in the aerated compartment of beans at the cooperative silo at KANAMA (January 1986-January 1987). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36	T37	T38	T39	T40	T41	T42	T43	T44	T45	T46	T47	T48	T49	T50	AVE
January	II	20.3	20.3	19.0	18.3	16.7	19.7	20.0	18.3	17.7	17.0	20.7	19.0	17.7	17.0	15.7	21.3	--	18.0	17.3	16.7	20.7	20.7	18.7	18.7	16.7	18.6
	III	17.4	17.1	16.5	16.6	16.3	16.4	16.4	15.8	16.1	16.1	15.8	15.6	16.0	16.1	15.1	19.8	18.0	16.4	16.0	16.0	18.3	17.6	17.1	17.3	16.6	16.7
February	II	18.3	18.1	18.0	17.8	17.4	16.8	18.0	17.0	17.3	17.4	17.0	17.0	17.0	17.4	15.1	19.0	18.4	18.0	17.5	17.5	18.3	18.8	18.0	18.0	17.9	17.6
	III	18.7	18.0	17.8	17.5	16.0	17.0	17.2	16.3	16.5	16.0	16.2	16.2	15.8	16.0	14.5	18.2	17.3	16.8	16.0	16.3	18.0	17.8	17.3	17.7	17.0	16.9
March	I	18.0	17.3	17.0	16.4	16.3	16.1	16.6	15.9	16.1	15.7	15.3	15.7	15.7	16.0	14.1	17.7	16.3	16.4	16.0	16.1	18.0	17.0	16.6	16.9	16.6	16.4
	II	18.4	18.2	17.4	17.0	16.2	16.9	16.8	16.4	16.6	16.1	16.0	16.0	16.0	16.0	15.3	17.6	16.9	16.8	16.4	16.1	17.9	17.2	17.0	17.0	16.9	16.8
	III	18.3	17.6	17.5	17.1	16.5	16.6	16.5	16.3	16.4	16.1	15.9	15.6	15.6	15.6	14.3	17.0	16.3	16.2	16.3	16.0	17.0	17.0	16.8	17.0	16.6	16.5
April	I	20.0	19.9	19.1	18.4	18.3	18.0	18.1	17.7	17.6	17.6	18.0	17.1	16.4	16.9	16.9	18.0	18.0	--	17.0	17.1	18.0	18.0	18.0	17.7	17.9	17.9
	II	20.0	19.5	19.0	18.6	18.1	18.1	18.0	17.9	17.8	17.6	17.1	17.1	17.0	17.5	16.9	18.3	18.0	--	17.8	17.5	18.1	18.1	18.0	18.1	17.9	18.0
	III	19.7	18.9	19.0	18.4	18.0	18.3	18.4	18.1	18.2	17.4	18.1	18.0	17.7	17.4	16.3	18.4	18.3	--	17.8	17.7	18.2	18.4	18.4	18.3	18.1	18.1
May	I	21.6	21.1	20.7	20.1	19.4	18.6	19.0	18.7	18.9	18.0	18.0	18.0	17.3	17.3	16.7	18.7	18.1	--	18.0	17.7	18.7	18.3	18.6	18.7	18.6	18.7
	II	21.0	20.9	20.7	19.9	19.3	18.6	19.1	19.1	18.9	18.3	18.0	17.9	17.9	17.4	17.1	18.7	18.9	--	18.1	18.0	18.9	18.9	18.7	18.6	18.3	18.8
	III	20.0	19.0	18.7	19.0	16.7	17.9	17.6	17.1	17.2	16.2	16.7	16.6	16.3	16.2	15.2	18.8	17.6	--	16.8	16.4	18.2	17.9	17.7	17.4	17.1	17.4
June	I	19.3	18.3	18.3	17.6	15.9	17.3	17.0	16.6	16.4	15.1	15.4	15.7	15.6	15.3	13.4	18.0	16.6	--	16.0	15.4	18.0	17.3	17.1	16.9	16.0	16.6
	II	20.0	18.8	18.6	17.2	16.7	17.2	16.8	16.4	16.6	15.9	15.3	15.3	15.6	15.8	14.3	17.7	16.2	--	16.1	15.9	17.7	17.0	16.8	16.6	16.6	16.7
	III	20.8	19.8	19.4	18.5	16.9	18.1	17.8	17.6	17.3	16.4	17.0	16.8	16.3	15.5	14.5	18.0	17.8	--	16.9	16.1	18.0	17.9	17.8	17.5	17.0	17.5
July	I	20.3	18.8	18.7	17.3	15.7	17.0	15.8	15.8	15.2	14.2	14.0	13.7	13.7	13.5	12.8	17.5	16.0	--	14.7	14.3	17.5	16.5	16.0	16.0	15.0	15.8
	II	20.4	19.1	18.9	18.0	15.9	17.0	16.8	16.6	15.9	14.6	14.8	14.9	14.8	14.0	13.3	17.1	16.3	--	15.3	14.5	17.0	17.0	16.8	16.3	16.1	16.3
	III	19.1	17.7	17.3	16.4	15.0	15.8	14.9	14.7	14.3	13.7	13.0	12.7	12.6	12.6	12.4	17.0	14.8	--	13.3	13.2	17.0	16.0	15.4	15.0	14.8	14.9
August	I	19.3	18.3	18.7	18.0	16.5	16.5	16.0	16.0	16.0	15.2	14.3	14.2	14.3	14.0	14.3	17.0	15.5	--	15.2	15.0	16.8	16.0	16.0	16.0	16.2	16.1
	II	20.1	18.5	18.5	17.6	16.3	16.8	15.8	15.5	15.3	15.0	13.4	13.3	13.6	13.6	13.9	17.0	15.3	--	14.4	14.5	17.0	16.0	16.1	16.0	16.0	15.8
	III	21.9	20.4	20.6	19.3	17.8	17.8	17.0	16.7	16.4	16.2	14.6	14.7	14.3	14.4	15.4	17.3	16.0	--	15.1	15.6	17.6	16.9	17.1	17.3	17.2	17.0
September	I	19.4	19.0	19.0	18.8	18.8	17.0	17.0	17.0	16.9	17.8	15.3	15.6	15.8	16.0	16.0	17.9	16.4	--	16.0	16.8	18.0	17.3	17.1	17.6	17.4	17.2
	II	19.3	19.0	19.6	19.4	18.2	17.2	17.1	17.2	17.6	17.6	15.6	15.6	15.9	16.4	16.1	18.0	17.0	--	16.4	17.1	18.0	17.1	17.1	17.6	17.2	17.4
	III	20.1	19.7	19.7	19.3	17.6	17.3	17.1	17.0	17.3	16.9	15.6	15.4	15.1	16.1	15.1	18.0	17.0	--	16.0	16.7	18.0	17.7	17.1	17.4	17.6	17.3
October	I	20.1	20.0	20.1	19.8	18.3	18.0	17.4	17.6	17.9	17.4	15.9	16.1	15.9	17.1	15.9	18.2	17.2	--	16.9	17.3	18.2	17.8	17.8	18.0	18.2	17.8
	II	19.5	19.8	19.9	19.8	18.3	18.0	18.0	17.8	18.4	17.1	16.9	16.5	16.5	17.1	16.1	18.9	18.0	--	17.4	17.1	18.9	18.3	18.0	18.4	18.4	18.0
	III	19.6	19.6	19.7	19.1	17.7	17.8	17.2	17.6	18.0	17.0	16.4	16.3	16.1	16.9	15.3	18.9	17.6	--	17.3	17.3	18.9	18.1	18.1	18.1	18.1	17.8
November	I	19.3	18.3	18.7	18.0	16.5	16.5	16.0	16.0	16.0	15.2	14.2	14.3	14.3	14.0	13.8	17.0	15.5	--	15.2	14.8	17.0	16.0	16.0	16.0	16.2	16.0
	II	19.0	18.4	18.2	17.8	16.0	17.3	16.7	16.3	16.3	15.6	15.6	14.9	14.8	15.1	14.3	18.0	17.0	--	15.8	15.4	17.8	17.3	17.2	17.0	16.7	16.6
	III	18.4	18.5	18.5	18.0	17.0	17.0	17.0	17.0	17.3	16.4	15.8	15.8	16.0	16.3	15.5	18.0	17.0	--	17.0	16.8	18.0	18.0	17.8	18.0	17.4	17.2
December	I	18.2	18.0	17.9	18.0	17.9	17.1	17.1	17.4	18.0	17.4	16.9	16.1	17.0	17.0	16.2	18.0	17.9	--	18.0	17.6	18.9	18.3	18.0	18.1	17.9	17.6
	II	17.6	17.3	17.3	17.2	16.8	16.7	17.1	17.0	17.2	16.6	17.0	16.4	17.0	17.1	15.6	18.1	18.1	--	18.1	17.9	18.6	18.2	18.0	17.7	17.2	17.3
	III	18.3	18.5	18.5	18.4	17.0	17.5	17.4	17.5	17.8	16.6	16.9	16.6	16.6	17.0	16.1	18.5	17.9	--	17.6	17.4	18.3	18.3	18.0	17.9	17.5	17.6
January	I	18.0	17.9	17.9	17.4	15.8	17.0	16.6	16.6	16.8	15.1	15.9	15.6	15.8	15.4	14.1	18.0	17.4	--	16.4	15.6	18.0	17.6	17.4	17.3	16.3	16.7
	II	17.0	17.0	17.0	17.0	15.5	16.5	16.0	16.5	16.0	14.5	15.0	15.0	15.5	15.5	13.5	18.0	16.5	--	16.0	15.5	17.5	17.0	17.0	17.0	16.0	16.2
Average		19.4	18.8	18.7	18.1	17.0	17.3	17.1	16.9	17.0	16.3	16.0	15.9	15.8	15.9	15.0	18.1	17.1	16.9	16.4	16.3	18.0	17.6	17.4	17.4	17.0	17.1

Table 5.4. Changes observed in some physical characteristics (moisture content, test weight and foreign material) of dry edible beans (Phaseolus vulgaris) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Physical Charact.	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Moisture content (%, w.b.)	A Bottom	16.1	15.4	14.6	14.3	14.5
	A Middle	15.0	14.8	14.5	13.6	13.8
	A Top	15.6	16.5	14.9	13.6	16.9
	A Mean	15.6	15.5	14.7	13.8	15.1
	NA Bottom	15.9	16.3	15.8	15.2	15.8
	NA Middle	16.0	15.9	15.9	15.5	16.3
	NA Top	15.6	15.5	15.5	15.3	16.2
	NA Mean	15.8	15.9	15.7	15.3	16.1
	Total Mean	15.7	15.7	15.2	14.6	15.6
Test weight (kg/m^3)	A Bottom	734.1	726.7	716.7	742.1	730.2
	A Middle	726.8	717.4	712.0	723.8	721.8
	A Top	732.0	718.3	718.3	735.1	716.2
	A Mean	731.0	720.8	715.6	733.7	722.8
	NA Bottom	733.4	732.8	720.8	722.5	718.4
	NA Middle	729.7	731.4	718.3	731.7	711.6
	NA Top	736.9	708.1	697.2	704.7	702.0
	NA Mean	733.4	724.1	712.1	719.6	710.6
	Total Mean	732.2	722.5	713.9	726.6	716.7
Foreign material (%)	A Bottom	1.83	1.25	2.79	2.28	2.91
	A Middle	1.60	1.46	6.96	2.13	1.66
	A Top	0.57	0.56	1.39	0.98	0.79
	A Mean	1.33	1.09	3.71	1.80	1.79
	NA Bottom	2.30	4.65	2.44	2.30	2.71
	NA Middle	1.57	1.54	1.21	1.65	1.52
	NA Top	1.52	1.30	1.03	1.08	0.61
	NA Mean	1.80	2.50	1.56	1.68	1.61
	Total Mean	1.56	1.79	2.64	1.74	1.70

Table 5.5. Changes observed in some quality factors (total number of insects per kg., number of live insects per kg. and percentage damaged by insects - *Acanthoscelides obtectus* and *Zabrotes subfasciatus*) of dry edible beans (*Phaseolus vulgaris*) stored during a period of 12 months in an aerated (A) and an non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, center and top - within each compartment.

Quality Factor	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Total number of insects per kg of beans	A Bottom	42.1	21.2	30.4	118.7	60.9
	A Middle	27.5	15.2	59.9	65.2	70.4
	A Top	13.6	1.3	11.4	16.1	7.6
	A Mean	27.7	12.6	33.9	66.7	46.3
	NA Bottom	48.3	60.7	22.7	49.0	17.7
	NA Middle	84.6	5.0	25.3	63.3	21.7
	NA Top	51.8	11.5	0.0	9.0	5.2
	NA Mean	61.6	25.7	16.0	40.4	14.9
	Total Mean	44.6	19.2	25.0	53.6	30.6
Number of live insects per kg of beans	A Bottom	3.7	0.0	0.0	0.0	0.0
	A Middle	1.2	0.0	0.0	0.0	0.0
	A Top	2.5	0.0	0.0	0.0	0.0
	A Mean	2.5	0.0	0.0	0.0	0.0
	NA Bottom	13.6	0.0	0.0	0.0	0.0
	NA Middle	22.4	0.0	0.0	0.0	0.0
	NA Top	9.9	0.0	0.0	0.0	0.0
	NA Mean	15.3	0.0	0.0	0.0	0.0
	Total Mean	8.9	0.0	0.0	0.0	0.0
Percentage insect damaged beans	A Bottom	1.7	0.3	1.7	2.0	1.7
	A Middle	1.3	0.0	0.0	0.7	3.7
	A Top	1.7	1.0	1.0	0.7	0.3
	A Mean	1.6	0.4	0.9	1.1	1.9
	NA Bottom	3.3	1.0	0.0	0.0	1.0
	NA Middle	1.7	0.7	0.7	0.3	0.3
	NA Top	1.3	1.0	0.7	0.7	1.0
	NA Mean	2.1	0.9	0.5	0.3	0.8
	Total Mean	1.8	0.7	0.7	0.7	1.3

Table 5.6. Changes observed in some damage categories (percent beans damaged by visible molds or by rodents and sprouted beans) of dry edible beans (Phaseolus vulgaris) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Visible mold damage (%)	A Bottom	1.3	1.0	0.7	1.0	1.0
	A Middle	1.7	3.0	2.0	2.6	2.3
	A Top	1.3	1.7	0.7	2.0	1.7
	A Mean	1.4	1.9	1.1	1.9	1.7
	NA Bottom	2.0	1.0	0.7	0.7	1.7
	NA Middle	0.7	1.0	2.3	1.0	0.7
	NA Top	1.0	1.0	0.0	2.3	1.3
	NA Mean	1.2	1.0	1.0	1.3	1.2
	Total Mean	1.3	1.4	1.1	1.6	1.4
Rodent damage (%)	A Bottom	0.0	0.0	0.0	0.0	1.7
	A Middle	0.0	0.3	0.0	0.7	0.7
	A Top	0.0	0.0	0.0	0.7	0.0
	A Mean	0.0	0.1	0.0	0.5	0.8
	NA Bottom	0.3	0.0	0.3	0.7	0.0
	NA Middle	1.0	0.3	0.0	0.7	1.0
	NA Top	0.3	0.7	0.7	0.7	0.3
	NA Mean	0.5	0.3	0.3	0.7	0.4
	Total Mean	0.3	0.2	0.2	0.6	0.6
Sprouted beans (%)	A Bottom	0.0	0.0	0.0	0.0	0.3
	A Middle	0.0	0.0	0.0	0.3	0.7
	A Top	1.0	0.3	0.0	0.3	0.0
	A Mean	0.3	0.1	0.0	0.2	0.3
	NA Bottom	0.0	0.0	0.0	0.0	0.0
	NA Middle	0.0	0.0	0.0	0.0	0.3
	NA Top	0.0	0.0	0.0	0.0	0.0
	NA Mean	0.0	0.0	0.0	0.0	0.1
	Total Mean	0.2	0.0	0.0	0.1	0.2

Table 5.7. Changes observed in some damage categories (percent broken beans, discolored beans or beans with a torn pericarp) of dry edible beans (*Phaseolus vulgaris*) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Broken beans (%)	A Bottom	1.7	1.3	1.3	1.0	1.3
	A Middle	2.3	1.7	2.0	1.0	0.7
	A Top	1.7	1.3	1.0	2.3	0.7
	A Mean	1.9	1.4	1.4	1.4	0.9
	NA Bottom	1.3	1.0	0.3	1.0	1.0
	NA Middle	0.3	2.3	0.3	1.3	0.7
	NA Top	0.3	0.3	1.7	2.3	0.3
	NA Mean	0.6	1.2	0.8	1.5	0.7
	Total Mean	1.3	1.3	1.1	1.5	0.8
Discolored beans (%)	A Bottom	10.0	12.0	9.3	27.6	26.0
	A Middle	16.3	7.0	8.0	21.3	27.7
	A Top	9.0	8.0	8.7	24.0	27.0
	A Mean	11.8	9.0	8.7	24.3	26.9
	NA Bottom	22.7	12.7	5.3	22.7	27.0
	NA Middle	11.7	15.0	8.7	19.6	26.7
	NA Top	17.3	14.0	9.0	29.0	27.7
	NA Mean	17.2	13.9	7.7	23.8	27.1
	Total Mean	14.5	11.4	8.2	24.0	27.0
Beans with torn pericarp (%)	A Bottom	0.3	0.7	1.3	1.3	1.3
	A Middle	1.3	1.0	1.0	1.6	0.3
	A Top	0.7	0.0	1.0	1.0	1.0
	A Mean	0.8	0.6	1.1	1.3	0.9
	NA Bottom	3.0	1.0	1.0	1.3	1.0
	NA Middle	0.7	1.0	1.0	1.3	1.3
	NA Top	1.7	2.0	1.0	1.3	0.3
	NA Mean	1.8	1.3	1.0	1.3	0.9
	Total Mean	1.3	0.9	1.1	1.3	0.9

Table 5.8. Changes observed in some damage categories (percent small, wrinkled or dented beans) of dry edible beans (<u>Phaseolus</u> <u>vulgaris</u>) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). Observations made at three locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Small beans (%)	A Bottom	10.0	13.3	9.7	14.0	12.3
	A Middle	10.3	10.0	9.0	19.0	10.7
	A Top	8.7	10.0	3.7	22.0	10.7
	A Mean	9.7	11.1	7.5	18.3	11.2
	NA Bas	7.3	11.0	6.3	17.6	13.0
	NA Middle	13.0	12.7	9.0	16.3	10.0
	NA Top	6.0	14.0	5.0	11.3	7.7
	NA Mean	8.8	12.6	6.8	15.1	10.2
	Total Mean	9.2	11.8	7.1	16.7	10.7
Wrinkled beans (%)	A Bottom	3.3	3.3	2.3	3.6	3.7
	A Middle	0.0	3.7	4.3	5.3	4.3
	A Top	4.0	3.7	4.3	5.3	4.3
	A Mean	2.4	4.4	4.6	6.5	4.1
	NA Bottom	5.0	8.7	5.3	6.6	4.7
	NA Middle	2.0	2.0	5.3	5.0	2.7
	NA Top	4.0	8.7	3.3	7.3	2.3
	NA Mean	3.7	6.5	4.6	6.3	3.2
	Total Mean	3.0	5.4	4.6	6.4	3.7
Dented beans (%)	A Bottom	7.3	1.0	7.3	2.3	3.7
	A Middle	4.7	2.3	6.0	6.0	2.7
	A Top	13.3	6.7	3.7	3.3	3.7
	A Mean	8.4	3.3	5.7	3.9	3.4
	NA Bottom	3.3	3.0	4.7	4.0	4.3
	NA Middle	2.7	4.3	5.7	4.0	1.0
	NA Top	1.0	5.7	10.0	6.3	2.7
	NA Mean	2.3	4.3	6.8	4.8	2.7
	Total Mean	5.4	3.8	6.2	4.3	3.0

Table 5.9. Changes observed in some quality indicators (percent beans with storage related damage and beans considered unfit for consumption or planting) of dry edible beans (*Phaseolus vulgaris*) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Qual. Indicator	Location	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Beans with storage related damage (%)	A Bottom	3.0	1.3	2.4	3.0	4.7
	A Middle	3.0	3.3	2.0	4.3	7.4
	A Top	4.0	3.0	1.7	3.7	2.0
	A Mean	3.3	2.5	2.0	3.7	4.7
	NA Bottom	5.6	2.0	1.0	1.4	2.7
	NA Middle	3.4	2.0	3.0	2.0	2.3
	NA Top	2.6	2.7	1.4	3.7	2.6
	NA Mean	3.9	2.2	1.8	2.4	2.5
	Total Mean	3.6	2.4	1.9	3.0	3.6
Beans unfit for consumption (%)	A Bottom	16.7	14.0	9.7	13.6	20.3
	A Middle	26.0	12.7	15.7	21.0	23.7
	A Top	13.3	14.7	9.7	19.0	20.3
	A Mean	18.7	13.8	11.7	17.9	21.4
	NA Bottom	20.3	22.7	15.7	13.0	19.7
	NA Middle	16.7	21.7	11.3	16.6	20.3
	NA Top	15.7	22.7	14.0	23.6	12.3
	NA Mean	17.6	22.4	13.7	17.7	17.4
	Total Mean	18.1	18.1	12.7	17.8	19.4
Beans unfit for planting (%)	A Bottom	24.3	21.7	22.3	25.6	28.3
	A Middle	34.0	22.7	21.3	32.6	30.3
	A Top	20.3	27.3	15.0	30.6	29.7
	A Mean	26.2	23.9	19.5	29.6	29.4
	NA Bottom	30.3	29.0	10.0	24.0	31.0
	NA Middle	27.3	30.0	18.3	28.6	29.0
	NA Top	23.0	33.0	22.3	35.3	23.3
	NA Mean	26.9	30.7	16.9	29.3	27.8
	Total Mean	26.5	27.3	18.2	29.4	28.6

Table 5.10. Changes observed in the mean instrumental hardness, the percentage hard-to-cook beans and the germination rate of dry edible beans (*Phaseolus vulgaris*) stored during a 12 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in KANAMA (high altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Characteristic	Position	Storage Period (months)				
		0.0	3.5	7.0	9.0	12.0
Mean instrum. hardness (Newton)	A Bottom	2.38	3.14	3.16	3.69	3.81
	A Middle	3.47	3.38	3.51	3.44	4.18
	A Top	3.29	3.32	3.15	3.53	3.40
	A Mean	3.05	3.28	3.27	3.55	3.80
	NA Bottom	3.22	2.69	3.61	3.54	3.66
	NA Middle	3.26	2.81	3.40	3.45	4.16
	NA Top	3.22	2.69	3.61	3.54	3.66
	NA Mean	3.23	2.73	3.54	3.51	3.82
	Total Mean	3.14	3.00	3.40	3.53	3.81
Percent hard-to-cook beans	A Bottom	7.0	21.0	21.0	35.0	45.0
	A Middle	28.0	24.0	36.0	30.0	57.0
	A Top	21.0	23.0	19.0	38.0	25.0
	A Mean	18.7	22.7	25.3	34.3	42.3
	NA Bottom	19.0	11.0	33.0	41.0	30.0
	NA Middle	19.0	11.0	32.0	34.0	53.0
	NA Top	24.0	12.0	28.0	35.0	26.0
	NA Mean	20.7	11.3	31.0	36.7	36.3
	Total Mean	19.7	17.0	28.2	35.5	39.3
Germination rate (%)	A Bottom			66.0	57.0	32.0
	A Middle			74.5	56.5	34.0
	A Top			77.0	41.0	42.0
	A Mean			72.5	51.5	36.0
	NA Bottom			55.5	39.5	14.0
	NA Middle			44.0	37.5	13.0
	NA Top			63.0	36.5	9.0
	NA Mean			54.2	37.8	12.0
	Total Mean			63.3	44.7	24.0

None of the other damage categories (Tables 5.6-5.8) changed except the category of discolored beans (Table 5.7). The percent discolored beans increased sharply between 7.0 and 9.0 months of storage. Discoloration is often linked to the aging process of the beans, just as is hardening. Interestingly enough there is no difference between the two compartments.

Interpretation of the discoloration results is under considerable discussion at this time. As originally defined for the storage survey (Dunkel et al., 1986), discolored beans were those having spotty or blotchy color aberations which could often be identified soon after harvest. The discolored bean category was not defined in terms of loss in brightness or browning which is normally associated with the aging of beans. However, the results from Table 5.7 (and those that follow in several other sections of this report) suggest that whatever is being interpreted as discoloration is increasing with time. Whether or not this discoloration is related to or an indication of the color changes associated with aging is being investigated.

The percentages of seeds with storage related damage and those found to be unfit for consumption or for planting did not change significantly over the 12 month storage period (Table 5.9). This indicates that the level of spoilage is extremely low. On the other hand the high level of so-called 'inedible' (18.1%) and 'unplantable' seeds (26.5%) at the beginning of the storage period strongly suggests that something should be done to clean the grain before it is placed into long-term storage. Appreciable amounts of space, time and money are wasted by storing a product that in the end will be thrown away.

The percent hard-to-cook beans started to increase and surpassed the 30% level between 7.0 and 9.0 months of storage, and this trend continued after 9.0 months (Table 5.10). By that time the beans were about 10 months old. The instrumental hardness data confirm the onset of hardening. No germination data at 0.0 months are available, but assuming the original values are somewhere up in the normal range observed in other stocks, they can be estimated to be between 85 and 95%. After one year of storage, the germination rate had fallen sharply to an average of 24%, with a greater decline in the NAC than in the AC.

5.1.2.2. Rusatira

The two compartments selected for this experiment were located in the southeast and northwest corners of the silo. The overall layout of this silo differs somewhat from the typical design in that its compartments are arranged in two blocks of three instead of one block of six compartments. The two blocks are separated by a corridor from which the emptying spouts can be reached. In addition the space between the top of the compartments and the roof is enclosed allowing less ventilation and exchange of air to the outside than the typical design.

The beans were placed in the silo on February 15, 1986. The last samples were drawn on January 13, 1987 or after 11 months of storage. They had the same origin as the beans stored in the Kanama silo. The aeration treatment had to be terminated in September 1986 because the generator broke down. The generator was not replaced because at that time it was judged that the aeration part of the experiment had attained its objectives and that continuation was not critical to the conclusions of this experiment.

The average ambient minimum and maximum temperatures (Table 5.1) during the time of this experiment were 18.0 and 27.9°C, respectively. Table 5.11 shows the ten-day temperature distributions measured in the non-aerated compartment (NAC). The average temperatures ranged from 23.0°C in the center (T13) to 19.0°C (T3-T4) at the outside corner. Temperatures near the outside wall (T1-T10) were lower than anywhere else. The temperature distribution in the aerated compartment (AC) was quite uniform (Table 5.12). The overall average temperature was 20.2°C in the NAC and 21.4°C in the AC.

There are two factors which may contribute to the lower average temperature in the NAC. One is that it had two walls exposed to the exterior while the AC had only one wall exposed to the exterior. The other is that because the space between the top of the compartment and roof is enclosed, aeration air drawn downward through the beans comes from within the silo enclosure rather than from outside. Residual heat in the structure is likely to increase the interior air temperature somewhat which, when drawn through the beans, would result in a slightly higher temperature for the AC.

Table 5.13 shows that the aeration treatment did not influence the MC of the beans. Only after 10 months of storage, and thus after the aeration had been halted and already well into the rainy season, was an average MC decline of 0.7% observed in the AC.

In spite of two fumigation treatments (on February 21 and October 8, 1986) live insects were found in the AC at each sampling, except the last one (Table 5.14). Especially the area near the emptying spout was very sensitive to reinfestation (observation made by visual inspection through the emptying spout). This is also confirmed by the 5% increase in the percentage of insect damaged beans near the bottom, which rose from 1.7 to 6.7% in just one month (Table 5.14). On the other hand, samples drawn from the NAC did not contain live insects. Both fumigations were conducted by experienced project staff who certainly applied the recommended rates and correctly distributed the tablets throughout the grain bulk. It was also standard procedure to sample fumigated compartments immediately after to check whether or not a 100% kill was attained. These tests did not reveal the presence of live insects. Nevertheless, both applications in the AC proved to be

Table 5.11. Ten-day mean temperatures (°C) in the non-aerated compartment of beans at the cooperative silo at RUSATIRA (April 1986 - January 1987). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	AVE
April	I	19.9	19.0	18.6	18.4	19.0	--	19.0	19.0	18.8	19.0	21.4	21.6	22.0	22.0	22.0	21.0	20.9	21.6	21.4	21.4	21.0	--	21.2	21.3	21	20.5
	II	19.5	19.1	18.9	18.9	19.0	--	19.3	19.9	19.9	19.4	20.6	20.5	21.5	22.0	21.4	20.3	21.1	21.1	20.8	20.9	21.0	--	21.0	21.0	21	20.4
	III	19.2	18.5	18.3	18.5	19.0	--	19.3	19.0	19.0	18.8	20.3	21.0	21.8	21.5	21.3	20.8	21.3	21.3	20.8	20.7	20.7	--	20.8	21.0	20.8	20.2
May	I	19.1	18.9	19.0	19.1	19.1	--	18.6	18.6	18.6	18.5	20.5	20.5	21.4	21.4	21.5	20.9	21.0	21.0	20.5	20.8	21.0	--	21.0	21.1	21.5	20.2
	II	19.5	18.8	18.2	18.8	18.8	--	19.0	18.8	18.3	18.7	20.5	21.3	21.5	21.2	21.3	21.0	21.8	22.0	21.3	21.5	20.8	--	21.8	21.5	21.8	20.4
	III	18.9	18.6	18.4	18.9	18.6	--	18.6	18.9	18.7	19.1	20.9	21.7	22.0	22.0	21.7	21.6	21.1	21.6	21.9	21.3	21.9	--	21.4	21.3	21.1	20.4
June	I	18.7	18.4	18.1	18.4	18.4	--	18.0	18.0	18.0	18.6	20.4	21.6	21.4	21.9	21.6	21.0	21.0	21.0	21.3	21.1	21.3	--	21.0	21.0	21.1	20.1
	II	18.4	18.3	18.2	18.8	19.3	--	18.3	18.9	19.7	20.2	20.9	20.6	21.0	20.9	21.2	21.2	21.1	20.7	21.3	21.2	21.1	--	21.1	21.0	20.9	20.2
	III	18.6	18.1	18.1	17.8	17.9	--	18.6	18.8	18.3	19.6	20.6	20.5	20.5	21.0	21.0	20.8	20.6	21.0	20.8	20.9	20.4	--	20.9	20.9	20.9	19.9
July	I	18.9	18.9	18.8	18.5	18.3	--	18.9	19.9	20.1	20.8	20.8	21.0	20.9	21.1	21.1	21.1	21.1	21.3	21.3	20.9	21.0	--	21.0	21.4	21.3	20.4
	II	19.0	19.1	19.1	18.8	18.4	--	18.6	19.0	19.3	20.0	20.8	21.3	21.0	20.6	20.6	20.8	21.0	20.9	21.0	21.1	20.8	--	21.1	21.6	21.8	20.2
	III	19.0	18.0	18.0	18.0	18.0	--	18.0	18.0	18.0	18.0	19.0	22.0	21.0	20.0	21.0	20.0	20.0	20.0	10.0	20.0	20.0	--	20.0	21.0	21.0	19.0
August	I	19.2	18.2	18.3	18.5	18.3	--	18.0	17.3	18.0	18.3	19.0	20.0	20.3	20.0	20.0	19.5	20.2	20.2	20.2	20.2	19.5	--	20.3	20.3	20.3	19.3
	II	20.0	19.7	19.0	18.8	18.9	--	18.2	18.3	18.9	18.6	19.1	19.7	19.7	20.8	21.0	20.2	20.3	20.0	20.7	21.1	20.8	--	20.8	21.3	21.3	19.9
	III	20.9	20.0	19.9	19.8	20.0	--	19.0	19.3	19.8	20.4	20.1	21.8	20.6	21.0	21.6	21.0	21.8	21.9	21.8	21.9	21.1	--	21.9	21.9	23.6	20.9
September	I	20.3	19.7	19.5	19.2	19.3	--	19.5	19.2	19.0	19.8	21.2	31.2	24.7	21.2	22.0	21.0	22.8	23.0	22.0	22.0	21.2	--	22.0	22.0	22.0	21.5
	II	20.0	19.0	19.0	19.0	20.0	--	19.3	19.0	19.0	19.0	22.3	31.7	29.3	24.0	22.0	21.0	23.7	24.0	22.3	22.0	21.3	--	22.0	22.0	22.0	21.9
	III	22.4	22.1	22.0	21.3	21.3	--	21.3	21.3	22.0	22.1	23.6	22.9	22.7	22.9	21.7	21.7	22.3	21.9	22.1	22.7	23.3	--	23.1	22.6	22.0	22.2
October	I	23.0	21.5	21.5	21.5	21.5	--	22.0	21.5	21.0	21.0	24.0	29.0	29.5	29.0	26.0	22.0	24.0	25.0	25.0	24.0	22.0	--	23.0	23.5	23.5	23.7
	II	22.3	21.0	20.5	21.0	21.0	--	21.0	21.0	21.0	21.0	23.0	23.8	25.3	26.3	27.0	22.0	23.0	24.0	24.0	21.0	21.8	--	23.0	22.3	22.0	22.5
	III	22.9	21.0	20.4	20.3	20.7	--	21.0	21.0	20.7	21.0	22.0	23.1	25.6	27.1	26.8	21.1	22.0	23.6	23.3	21.0	21.4	--	23.6	22.6	21.4	22.3
November	I	22.0	20.0	20.0	20.0	20.0	--	21.0	20.5	20.0	20.0	23.0	24.0	25.0	26.0	26.0	21.0	22.0	23.0	23.0	21.0	21.0	--	22.0	22.0	21.0	21.9
	II	21.1	19.3	19.1	19.1	19.1	--	20.1	20.7	19.9	20.1	22.1	23.1	24.6	24.7	25.1	20.1	21.1	22.0	22.3	21.9	20.3	--	20.9	21.1	20.4	21.2
	III	21.0	19.9	19.3	19.0	19.0	--	20.0	21.0	19.3	21.0	22.0	23.0	24.6	24.3	25.0	20.0	20.9	21.9	21.9	21.8	20.6	--	21.0	21.0	20.0	21.2
December	I	20.4	19.9	19.1	18.4	18.9	--	20.6	20.0	19.0	20.0	21.6	22.4	24.4	24.4	24.6	20.0	20.4	21.0	21.4	20.4	20.0	--	21.0	21.0	20.0	20.8
	II	20.0	18.1	18.0	18.0	18.9	--	20.0	19.0	19.0	18.0	21.1	22.0	24.0	24.0	24.0	20.0	21.0	21.0	22.0	21.0	20.0	--	21.0	21.0	20.0	20.5
	III	20.0	18.3	18.0	18.0	19.0	--	20.0	19.0	19.0	18.0	21.0	22.0	23.9	24.0	24.0	20.0	21.0	21.0	22.0	21.0	20.0	--	21.0	21.0	20.0	20.5
January	I	20.0	18.0	18.0	18.0	18.0	--	19.0	19.0	19.0	18.0	21.0	22.0	23.0	24.0	24.0	20.0	21.0	21.0	21.0	21.0	20.0	--	21.1	21.0	20.3	20.3
Average		20.2	19.3	19.0	19.0	19.2	--	19.4	19.4	19.3	19.5	21.2	22.7	23.0	22.8	22.7	20.8	21.4	21.7	21.3	21.3	20.9	--	21.4	21.5	21.2	20.2

Table 5.12. Ten-day mean temperatures (°C) in the aerated compartment of beans at the cooperative silo at RUSATIRA (April 1986 - January 1987). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36	T37	T38	T39	T40	T41	T42	T43	T44	T45	T46	T47	T48	T49	T50	AVE
April	I	21.0	21.0	21.0	21.1	20.9	20.2	20.1	20.3	20.3	20.2	20.4	20.6	20.4	20.2	20.4	20.7	20.8	21.1	21.0	20.9	20.8	21.0	21.0	21.0	20.9	20.7
	II	21.0	21.0	21.0	20.9	20.1	20.5	20.3	20.5	21.1	20.3	20.4	21.1	21.0	20.8	21.9	21.6	21.5	20.8	21.0	20.9	20.8	20.8	21.0	21.0	21.0	20.9
	III	21.0	21.0	21.0	21.0	20.5	20.5	20.0	20.7	20.5	20.7	21.2	21.0	21.0	20.8	20.7	20.5	21.0	20.7	20.3	20.5	20.8	20.8	20.7	20.7	20.7	20.7
May	I	21.1	21.1	21.5	21.4	20.8	20.8	20.8	20.9	21.1	21.0	20.8	20.8	21.0	21.3	20.5	20.8	21.1	20.6	20.9	20.6	21.4	20.8	21.1	20.8	21.1	21.0
	II	22.0	22.0	21.7	21.3	21.0	21.0	21.0	21.3	21.0	21.0	20.7	21.3	21.0	20.5	21.3	21.7	21.5	21.0	21.0	21.2	21.3	21.0	21.0	21.0	21.0	21.2
	III	22.0	21.6	21.4	21.4	21.6	21.6	21.0	20.7	20.6	20.6	21.7	21.7	21.4	21.0	21.6	21.4	21.3	21.3	20.9	21.3	21.4	21.4	21.1	21.0	21.6	21.3
June	I	21.6	21.7	21.7	21.0	21.0	20.9	21.1	21.0	20.7	20.4	21.3	21.3	20.7	20.9	20.9	21.0	21.0	20.7	20.5	20.5	21.0	21.0	20.3	20.5	20.5	20.9
	II	21.7	22.0	21.8	21.4	21.0	21.1	21.1	20.8	20.9	21.0	21.2	21.2	21.1	21.0	21.0	21.0	21.2	20.9	21.2	21.2	21.4	21.6	21.1	21.0	21.0	21.2
	III	21.8	21.8	21.6	21.8	21.6	21.1	21.0	21.1	21.1	21.3	21.4	21.4	21.3	20.9	21.0	21.0	21.3	21.3	21.3	21.3	21.3	21.3	21.1	21.3	21.3	21.3
July	I	21.9	21.6	21.3	21.9	21.6	21.9	22.1	22.0	22.0	21.3	21.0	21.5	22.0	22.1	22.1	22.3	22.0	22.6	22.8	22.1	22.0	21.9	21.8	21.6	22.3	21.9
	II	22.3	22.0	22.0	22.0	22.3	22.5	22.8	22.0	21.4	21.3	21.5	21.9	21.0	20.9	22.0	21.8	21.8	21.0	22.0	22.0	21.8	21.1	21.4	22.0	22.3	21.8
	III	22.0	22.0	22.0	22.0	22.0	22.0	21.0	22.0	22.0	22.0	20.0	22.0	22.0	22.0	22.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	22.0	21.5
August	I	21.0	21.0	21.3	21.3	21.3	21.0	20.7	21.3	21.5	21.3	20.3	21.0	21.3	21.0	21.7	20.8	20.2	20.2	20.7	21.3	20.7	20.3	20.3	21.0	21.3	21.0
	II	21.9	21.8	21.9	21.8	21.9	21.6	21.9	21.8	21.7	21.7	21.2	21.4	21.8	21.8	21.8	21.9	21.9	22.0	21.4	21.7	21.1	21.7	21.2	22.0	21.8	21.7
	III	22.1	22.3	22.6	23.1	22.5	22.0	22.5	22.1	22.8	22.5	21.8	22.0	22.4	22.4	23.1	22.5	22.6	22.6	22.6	22.4	22.3	22.0	22.0	22.5	23.0	22.4
September	I	24.0	22.3	22.5	23.7	22.8	22.2	22.0	22.0	22.0	22.0	21.8	21.8	22.0	22.7	22.3	23.0	23.2	22.5	21.8	21.8	22.0	22.0	22.0	22.0	22.3	22.3
	II	24.0	23.7	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0	23.0	23.0	23.0	23.7	24.0	23.7	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.5
	III	22.3	22.6	22.3	22.6	23.0	22.4	23.7	23.3	21.9	22.6	22.9	24.7	23.3	23.0	22.4	22.4	21.7	22.3	21.7	22.0	22.9	23.0	22.4	23.0	23.0	22.7
October	I	22.5	22.5	22.5	22.5	23.0	22.0	22.0	22.5	22.5	22.5	21.5	23.0	23.5	24.0	23.5	23.5	23.5	23.0	23.0	23.0	23.0	23.0	23.5	23.5	23.5	22.9
	II	22.0	22.0	21.3	21.3	21.8	22.3	22.5	23.5	23.0	23.5	22.8	22.3	22.5	22.5	23.3	22.3	22.3	23.0	22.0	22.0	22.0	23.0	23.0	22.8	23.0	22.5
	III	21.9	22.0	22.1	22.3	22.5	22.5	22.0	22.8	22.0	22.0	22.1	22.8	23.7	24.0	23.2	22.0	22.0	22.0	22.0	22.0	22.0	22.1	23.0	22.5	22.1	22.4
November	I	21.0	21.0	21.0	21.0	21.0	21.0	20.0	20.0	20.0	20.0	22.0	23.2	24.0	24.0	22.0	22.0	22.0	22.0	21.0	21.0	21.8	22.0	22.0	22.0	22.0	21.6
	II	21.0	20.1	20.1	20.3	20.1	20.3	19.3	19.9	19.9	20.0	21.1	21.4	23.1	23.0	21.1	21.1	21.1	21.1	21.0	21.0	21.1	21.1	21.1	21.1	20.3	20.8
	III	21.0	20.5	20.0	20.0	20.0	20.1	19.0	19.3	19.3	20.0	20.6	21.0	23.9	21.8	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.8	20.0	20.7
December	I	20.6	20.4	20.2	20.0	20.0	19.4	19.0	19.7	19.7	19.6	19.9	21.4	22.7	21.9	21.0	21.0	21.0	20.7	20.7	20.6	21.0	21.0	21.0	21.0	20.1	20.5
	II	20.0	20.0	20.0	20.0	20.0	20.0	19.0	19.0	19.0	19.0	20.6	22.0	23.0	23.0	21.0	21.0	21.0	21.0	21.0	20.9	21.0	21.0	21.0	21.0	20.1	20.6
	III	20.0	20.0	20.0	20.0	20.0	20.0	19.0	19.0	19.0	19.0	19.0	22.0	23.0	23.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.0	20.5
January	I	20.0	20.0	20.0	20.0	20.0	20.0	19.1	19.3	19.0	19.0	19.0	21.9	22.9	23.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.0	20.5
Average		21.6	21.5	21.4	21.4	21.3	21.2	20.9	21.1	21.0	21.0	21.1	21.8	22.1	22.0	21.7	21.6	21.6	21.5	21.4	21.4	21.5	21.5	21.4	21.5	21.4	21.4

Table 5.13. Changes observed in some physical characteristics (moisture content, test weight and foreign material) of dry edible beans (Phaseolus vulgaris) stored during a 11 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Physical Charact.	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Moisture content (%, w.b.)	A Bottom	15.1	15.1	15.8	15.4	15.5
	A Middle	16.1	16.1	15.6	14.6	14.9
	A Top	15.3	15.4	15.0	14.5	13.9
	A Mean	15.5	15.5	15.5	14.8	14.7
	NA Bottom	14.4	14.5	15.2	15.0	15.6
	NA Middle	14.7	14.8	15.6	15.7	15.0
	NA Top	15.6	15.7	13.9	14.8	14.3
	NA Mean	14.9	15.0	14.9	15.2	15.0
	Total Mean	15.2	15.2	15.2	15.0	14.9
Test weight (kg/m3)	A Bottom	749.7	746.2	745.9	734.1	713.5
	A Middle	739.9	738.7	718.8	717.6	705.0
	A Top	729.4	733.6	711.2	707.0	706.8
	A Mean	739.7	739.5	725.3	719.6	708.4
	NA Bottom	745.9	742.5	730.9	734.1	734.6
	NA Middle	746.5	747.2	718.4	711.1	704.1
	NA Top	730.1	731.7	722.3	724.7	710.1
	NA Mean	740.9	740.5	723.9	723.3	716.3
	Total Mean	740.3	740.0	724.6	721.4	712.4
Foreign material (%)	A Bottom	4.84	3.29	7.73	4.21	2.34
	A Middle	5.12	3.42	3.27	1.97	1.26
	A Top	1.64	1.29	0.91	1.52	0.81
	A Mean	3.87	2.67	3.97	2.57	1.47
	NA Bottom	2.59	2.35	4.33	1.10	2.99
	NA Middle	4.01	3.18	2.96	2.36	1.83
	NA Top	1.01	0.78	0.86	0.66	0.61
	NA Mean	2.54	2.10	2.72	1.37	1.81
	Total Mean	3.20	2.39	3.34	1.97	1.64

Table 5.14. Changes observed in some quality factors (total number of insects per kg., number of live insects per kg. and percentage of beans damaged by insects - Acanthoscelides obtectus and Zabrotes subfasciatus) of dry edible beans (Phaseolus vulgaris) stored during a period of 11 months in an aerated (A) and an non-aearated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, Middle and top - within each compartment.

Quality Factor	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Total number of insects per kg of beans	A Bottom	58.1	20.7	20.7	85.4	87.8
	A Middle	47.9	16.0	48.0	48.1	47.7
	A Top	18.7	7.4	14.0	16.7	3.9
	A Mean	41.6	14.7	27.6	50.0	46.4
	NA Bottom	53.6	13.5	38.5	33.4	75.4
	NA Middle	45.0	10.9	15.2	69.0	83.8
	NA Top	26.1	9.9	5.0	7.5	5.1
	NA Mean	41.6	11.4	19.6	36.6	54.8
	Total Mean	41.6	13.1	23.6	43.3	50.6
Number of live insects per kg of beans	A Bottom	3.6	2.4	0.0	2.5	0.0
	A Middle	0.0	0.0	0.0	2.5	0.0
	A Top	0.0	0.0	1.3	0.0	0.0
	A Mean	1.2	0.8	0.4	1.7	0.0
	NA Bottom	2.4	0.0	0.0	0.0	0.0
	NA Middle	0.0	0.0	0.0	0.0	0.0
	NA Top	0.0	0.0	0.0	0.0	0.0
	NA Mean	0.8	0.0	0.0	0.0	0.0
	Total Mean	1.0	0.4	0.2	0.8	0.0
Percentage insect damaged beans	A Bottom	1.3	1.3	0.7	1.7	6.7
	A Middle	1.3	1.3	1.3	2.0	1.7
	A Top	2.3	2.7	0.0	1.0	2.0
	A Mean	1.6	1.8	0.7	1.6	3.5
	NA Bottom	2.3	1.7	1.0	0.0	2,3
	NA Middle	0.0	0.0	0.7	1.3	1.3
	NA Top	2.3	2.7	2.0	0.0	2.3
	NA Mean	1.5	1.5	1.2	0.4	2.0
	Total Mean	1.6	1.6	0.9	1.0	2.7

Table 5.15. Changes observed in some damage categories (percent beans damaged by visible molds or by rodents and sprouted beans) of dry edible beans (*Phaseolus vulgaris*) stored during a 11 month period in an aerated (A) and a non-aerated compartment (NA) of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Visible mold damage (%)	A Bottom	4.0	3.3	2.7	1.0	5.0
	A Middle	1.3	1.0	3.0	1.0	4.3
	A Top	2.7	2.3	3.3	1.7	2.7
	A Mean	2.7	2.2	3.0	1.2	4.0
	NA Bottom	4.0	2.0	2.3	1.3	3.3
	NA Middle	3.7	3.7	2.0	1.3	2.3
	NA Top	2.7	1.7	2.3	0.0	3.7
	NA Mean	3.5	2.5	2.2	0.9	3.1
	Total Mean	3.1	2.3	2.6	1.1	3.5
Rodent damage (%)	A Bottom	0.0	0.0	1.0	1.0	2.0
	A Middle	0.0	0.0	0.7	0.3	1.0
	A Top	0.3	0.7	0.7	0.7	1.0
	A Mean	0.1	0.2	0.8	0.7	1.3
	NA Bottom	0.0	0.0	1.3	0.3	1.7
	NA Middle	0.3	0.3	0.7	0.7	1.0
	NA Top	0.0	0.0	1.3	0.3	2.3
	NA Mean	0.1	0.1	1.1	0.4	1.7
	Total Mean	0.1	0.2	0.9	0.5	1.5
Sprouted beans (%)	A Bottom	0.0	0.0	0.0	0.7	0.3
	A Middle	0.0	0.0	0.0	0.3	0.3
	A Top	1.0	1.7	1.3	1.0	0.0
	A Mean	0.3	0.6	0.4	0.7	0.2
	NA Bottom	0.3	0.3	0.0	0.0	0.3
	NA Middle	0.7	0.3	0.0	0.3	0.3
	NA Top	0.3	0.0	0.0	0.0	0.7
	NA Mean	0.4	0.2	0.0	0.1	0.4
	Total Mean	0.4	0.4	0.2	0.4	0.3

Table 5.16. Changes observed in some damage categories (percent broken beans, discolored beans or beans with a torn pericarp) of dry edible beans (*Phaseolus vulgaris*) stored during a 11 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Broken beans (%)	A Bottom	1.0	1.3	1.7	1.7	1.3
	A Middle	1.3	1.0	2.3	1.7	0.7
	A Top	1.0	0.0	1.0	2.3	1.0
	A Mean	1.1	0.8	1.7	1.9	1.0
	NA Bottom	0.0	1.0	1.7	0.3	1.0
	NA Middle	0.0	0.3	2.0	1.3	0.3
	NA Top	1.0	2.7	2.7	1.0	0.7
	NA Mean	0.3	1.3	2.1	0.9	0.7
	Total Mean	0.7	1.1	1.9	1.4	0.8
Discolored Beans (%)	A Bottom	6.3	7.0	22.3	28.0	27.7
	A Middle	25.0	22.3	22.7	27.7	30.0
	A Top	2.7	4.3	25.7	21.3	23.7
	A Mean	11.3	11.2	23.6	25.7	27.1
	NA Bottom	4.0	7.7	14.7	31.0	24.3
	NA Middle	11.7	11.0	33.3	32.0	27.3
	NA Top	5.3	16.0	26.3	34.3	34.3
	NA Mean	6.2	8.0	21.3	29.8	28.6
	Total Mean	8.8	9.6	22.4	27.7	27.9
Beans with torn pericarp (%)	A Bottom	1.0	1.7	2.0	1.0	1.0
	A Middle	1.3	1.3	3.0	0.7	0.7
	A Top	1.7	2.0	1.3	0.7	1.3
	A Mean	1.3	1.7	2.1	0.8	1.0
	NA Bottom	0.7	0.0	3.0	1.3	0.3
	NA Middle	0.3	0.7	1.3	0.7	0.7
	NA Top	0.7	1.3	1.0	0.7	0.7
	NA Mean	0.6	0.7	1.8	0.9	0.6
	Total Mean	0.9	1.2	1.9	0.8	0.8

Table 5.17. Changes observed in some damage categories (percent small, wrinkled or dented beans) of dry edible beans (Phaseolus vulgaris) stored during a 11 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). Observations made at three locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Small beans	A Bottom	11.7	11.0	13.3	14.0	15.7
(%)	A Middle	3.7	5.7	11.3	8.3	19.3
	A Top	4.0	8.7	14.0	8.7	12.7
	A Mean	6.5	8.5	12.9	10.3	15.9
	NA Bottom	3.0	7.7	13.3	11.0	14.3
	NA Middle	7.7	7.7	13.7	11.3	13.0
	NA Top	4.0	6.3	13.7	13.7	12.7
	NA Mean	4.9	7.2	13.6	12.0	13.3
	Total Mean	5.7	7.8	13.2	11.2	14.6
Wrinkled beans	A Bottom	3.0	3.7	3.7	4.7	6.0
(%)	A Middle	6.0	6.0	2.0	4.3	2.0
	A Top	5.3	7.0	5.3	4.3	3.0
	A Mean	4.8	5.6	3.7	4.4	3.7
	NA Bottom	5.7	9.0	4.3	3.7	2.3
	NA Middle	4.0	4.7	8.3	5.7	5.7
	NA Top	3.0	5.3	3.7	3.3	4.7
	NA Mean	4.2	6.3	5.4	4.2	4.2
	Total Mean	4.5	6.0	4.5	4.3	4.0
Dented beans	A Bottom	13.0	12.3	2.3	5.0	3.3
(%)	A Middle	5.0	5.3	4.0	5.3	4.3
	A Top	16.3	15.3	5.0	8.0	2.7
	A Mean	11.4	11.0	3.8	6.1	3.4
	NA Bottom	9.3	8.3	5.0	3.7	1.7
	NA Middle	8.3	8.0	7.3	4.0	6.3
	NA Top	11.3	13.0	3.7	3.3	2.7
	NA Mean	9.6	9.8	5.3	3.7	3.6
	Total Mean	10.5	10.4	4.5	4.9	3.5

Table 5.18. Changes observed in some quality indicators (percent with storage related damage and beans considered unfit for consumption or planting) of dry edible beans (Phaseolus vulgaris) stored during a 11 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Qual.Indicator	Location	Storage Period (months)				
		0.0	2.5	7.0	10.0	11.0
Beans with storage related damage (%)	A Bottom	5.3	4.6	4.4	4.4	14.0
	A Middle	2.6	2.3	5.0	3.6	7.3
	A Top	6.3	7.4	5.3	4.4	5.7
	A Mean	4.7	4.8	4.9	4.1	9.0
	NA Bottom	6.6	4.0	4.6	1.6	7.6
	NA Middle	4.7	4.3	3.4	3.6	4.9
	NA Top	5.3	4.4	5.6	0.3	9.0
	NA Mean	5.5	4.2	4.5	1.8	7.2
	Total Mean	5.1	4.5	4.7	3.0	8.1
Beans unfit for consumption (%)	A Bottom	15.7	15.3	13.7	18.3	24.0
	A Middle	34.7	27.7	13.3	17.7	20.0
	A Top	17.7	21.3	12.3	18.3	19.7
	A Mean	22.7	21.4	13.1	18.1	21.2
	NA Bottom	13.3	15.3	11.7	19.0	24.0
	NA Middle	12.0	13.3	12.3	19.3	22.3
	NA Top	14.0	16.7	12.3	17.7	24.3
	NA Mean	13.1	15.1	12.1	18.7	23.5
	Total Mean	17.9	18.3	12.6	18.4	22.4
Beans unfit for planting (%)	A Bottom	23.7	23.7	22.3	29.3	36.3
	A Middle	41.0	36.0	21.0	29.0	29.3
	A Top	27.7	31.0	16.7	29.0	28.7
	A Mean	30.8	30.2	20.0	29.1	31.4
	NA Bottom	20.3	27.0	18.3	30.7	31.7
	NA Middle	17.7	21.0	18.3	32.7	30.3
	NA Top	17.7	26.3	20.0	28.7	34.7
	NA Mean	18.6	24.8	18.9	30.7	32.2
	Total Mean	24.7	27.5	19.4	29.9	31.8

Table 5.19. Changes observed in the mean instrumental hardness, the percentage hard-to-cook beans and the germination rate of dry edible beans (Phaseolus vulgaris) stored during a 11 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSATIRA (medium altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Characteristic	Position	Storage period (months)				
		0.0	2.5	7.0	10.0	11.0
Mean instrum. hardness (Newton)	A Bottom		3.20	2.94	3.96	3.91
	A Middle		3.46	3.08	3.43	3.79
	A Top		2.97	3.45	3.88	3.66
	A Mean		3.21	3.16	3.76	3.79
	NA Bottom		3.20	3.41	3.68	3.92
	NA Middle		3.56	3.37	3.70	3.88
	NA Top		3.44	3.42	3.88	3.67
	NA Mean		3.40	3.40	3.75	3.82
	Tot Mean	3.14	3.30	3.28	3.75	3.80
Percent hard-to-cook beans	A Bottom		27.0	18.0	35.0	45.0
	A Middle		18.0	20.0	25.0	46.0
	A Top		18.0	35.0	43.0	39.0
	A Mean		21.0	24.3	34.3	43.3
	NA Bottom		24.0	35.0	26.0	48.0
	NA Middle		39.0	28.0	24.0	51.0
	NA Top		30.0	30.0	42.0	37.0
	NA Mean		31.0	31.0	30.7	45.3
	Tot Mean	19.7	26.0	27.7	32.5	44.3
Germination rate (%)	A Bottom			50.5	40.0	21.0
	A Middle			35.5	71.5	31.0
	A Top			43.5	60.0	32.0
	A Mean			43.2	57.2	28.0
	NA Bottom			44.5	64.0	16.0
	NA Middle			23.0	52.0	15.0
	NA Top			57.5	67.0	60.0
	NA Mean			41.7	61.0	30.3
	Tot Mean			42.4	59.1	29.2

ineffective in the long run. It is also possible that a reinfestation took place through the fan opening or the man hole.

Mold damage seemed to have increased in the middle and bottom layers of the AC (Table 5.15). The percentage discolored beans increased on average from 8.8 to 27.9% over the 11 month period (Table 5.16). This may be an indication of aging of the beans (see discussion in preceding section). The total mean percentage small beans increased by 8.9% while the percentage dented grains decreased by 7.0% (Table 5.17). There is, however, no reason to believe that the changes in these last two damage categories can be related to storage conditions. It is believed that this is the result of the sample variability and small but gradual changes in some of the more subjective aspects of this damage analysis procedure. None of the other damage categories showed significant changes.

The percentage grains with storage related damage increased in both compartments: from 4.7 to 9.0% in the AC and from 5.5 to 7.2% in the NAC (Table 5.18). The estimated average increase for both compartments combined was 3.0%, but because of the observed variability this number may well be higher.

After 11.0 months of storage there was no difference observed between the two compartments in the percent grains unfit for consumption or planting (Table 5.18). Both factors are considered to be rather high, at 22.4 and 31.8%, respectively. It should be emphasized here that the data show considerable variability, with most of the results measured after 7.0 months significantly lower than those measured either at the beginning of the experiment or after 2.5 months. This indicates that during this stage of the project, as the staff became more acquainted with the subject matter, small adjustments were made in the appraisal of bean quality and/or that, with new staff being assigned to this task, the test results were still quite dependent on who actually performed the test. In the AC no changes were observed in these two quality indicators over the storage period, except at the 7.0 month observations. In the NAC, however, there was more of a gradually increasing trend.

No initial hardness data were taken due to a misunderstanding. Because the beans used in the parallel experiment in Kanama had the same origin and were kept in the same environment as these beans until they were put in their respective silos, the average initial hardness parameters measured on the beans in Kanama are used here as reference values. The percent hard-to-cook beans surpassed the 30% level after close to 10.0 months of storage (Table 5.19). At that time the beans were about one year old. No significant differences were noted between the compartments. From the time germination data are available, i.e., after 7.0 months of storage, the results show that the germination rate was low in general (Table 5.19).

5.1.2.3. Rusumo

The experiment started on May 28, 1986. The last samples were drawn on January 9, 1987 after 7.5 months of storage. The beans were produced locally and purchased by the cooperative in February 1986. Both compartments were fumigated on May 29, 1986 and again around October 15, 1986.

The average ambient minimum and maximum temperatures (Table 5.1) during the time of this experiment were 16.3 and 28.5°C, respectively. Table 5.20 shows the ten-day temperature distribution measured in the non-aerated compartment (NAC). The average temperature ranged from 21.2°C near the center (T12) to 18.4°C at the top near the outside (T10). Temperatures at the top layer were generally cooler, probably because the thermocouples were exposed to the air. Average temperatures in the aerated compartment (AC) ranged from 16.8°C in the center (T38) to 20.7°C at several locations near the bottom (T27 and T46 in Table 5.21). The overall average temperature was 20.2°C in the NAC compared to 19.1°C in the AC.

The moisture content in the AC decreased 1.2 percentage points throughout the test increasing slightly at the end (Table 5.22). The moisture content of the NAC remained essentially constant.

The number of insects increased in the AC and live insects were even found in the top at the last sampling (Table 5.23). However, the percentage of insect damaged beans remained relatively low.

There was little change in mold and rodent damage or sprouted beans (Table 5.24) or in broken beans and beans with torn pericarp (Table 5.25). However, there was a marked increase in discolored beans in both compartments between the 3.0 and 5.5 month samplings (Table 5.25). The percentage of small beans found was variable from sampling to sampling and increased with time in both compartments (Table 5.26). However, there is no reason to believe these changes were related to storage conditions.

There was little change in beans with storage related damage or beans unfit for consumption or planting (Table 5.27). The percent hard-to-cook at the beginning of the test (mean of 34.2%) was already at the baseline level of approximately 30% and changed little during the 7.5 months of storage (Table 5.28). The instrumental hardness results confirm this. Contrary to Kanama and Rusatira, germination remained high throughout the test.

5.1.2.4. Gikoro

The experiment at Gikoro compared aerated and non-aerated storage of sorghum. The initial sampling was on December 17, 1985 (0 months) with subsequent samplings on February 8, 1986 (2.5 months), June 20, 1986 (6 months), August 14, 1986 (8 months) and

Table 5.20. Ten-day mean temperatures (°C) in the non-aerated compartment of beans at the cooperative silo at RUSUMO (June-November 1986). Thermocouple locations defined in Fig. 5.1. (I, II and III - first, second and third 10-day period, respectively.)

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	AVE
June	II	20.0	20.0	20.0	20.0	18.5	19.8	19.8	19.8	19.8	18.5	21.3	21.5	21.0	20.3	18.5	21.3	20.8	21.0	20.3	18.5	21.8	21.5	21.0	20.5	20.0	20.2
	III	19.8	19.9	19.9	19.9	17.9	19.8	19.6	19.9	19.9	17.5	21.3	21.3	21.0	20.5	17.9	21.9	21.1	20.5	20.0	18.1	21.9	21.3	20.9	20.1	19.9	20.1
July	I	19.2	19.2	19.6	19.4	17.4	18.8	18.4	19.0	19.0	16.8	21.2	21.4	21.0	20.4	17.4	21.4	20.6	20.2	19.6	17.6	21.4	20.8	20.4	20.0	19.4	19.6
	II	19.5	19.5	19.9	19.8	17.9	18.8	19.0	19.0	19.0	17.9	21.0	21.0	20.6	20.0	17.8	21.0	20.4	19.5	19.6	17.8	21.4	20.6	20.0	19.5	19.5	19.6
	III	18.3	19.0	19.0	19.0	17.3	18.0	18.0	18.3	18.3	17.0	21.0	21.0	21.0	20.0	17.3	21.0	20.0	19.0	19.0	17.3	21.0	20.0	20.0	19.0	18.3	19.1
August	I	20.8	21.0	21.0	20.2	19.8	20.0	19.6	20.0	19.6	19.0	20.6	20.8	20.8	20.2	19.0	21.0	20.0	20.0	20.0	20.0	21.0	20.6	20.0	20.0	20.0	20.2
	II	21.0	21.0	21.0	21.0	20.0	21.0	21.0	21.0	21.0	19.0	21.0	21.0	20.0	20.0	20.0	21.0	20.0	20.0	20.0	20.0	21.0	21.0	20.0	21.0	21.0	20.6
	III	22.0	22.0	22.0	22.0	20.7	21.0	21.7	21.9	21.9	20.6	20.9	21.0	21.0	20.9	21.0	20.9	20.9	20.7	20.7	20.9	20.9	21.0	21.0	21.0	21.3	21.2
October	I	22.8	22.8	21.8	22.3	20.3	23.0	23.0	23.0	22.5	20.0	21.0	21.0	21.0	21.0	19.5	20.0	20.0	20.0	20.0	19.5	20.3	20.0	20.0	20.3	20.5	21.0
	II	21.5	21.5	21.5	21.5	19.0	22.0	22.0	22.0	21.5	18.5	21.0	21.0	21.0	20.5	18.0	20.0	20.0	20.0	20.0	18.5	20.5	20.0	20.0	20.0	19.5	20.4
November	I	22.3	22.2	21.3	21.3	19.2	21.8	22.3	22.0	21.3	19.0	21.5	21.7	21.3	20.8	18.3	20.3	20.3	19.7	19.7	17.6	20.5	20.5	20.3	20.0	19.0	20.6
Average		20.7	20.7	20.6	20.6	18.9	20.4	20.4	20.5	20.3	18.5	21.1	21.2	20.9	20.4	18.6	20.9	20.4	20.1	19.9	18.7	21.1	20.7	20.3	20.1	19.9	20.2

Table 5.21. Ten-day mean temperatures (°C) in the aerated compartment of beans at the cooperative silo at RUSUMO (June-November 1986). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36	T37	T38	T39	T40	T41	T42	T43	T44	T45	T46	T47	T48	T49	T50	AVE
June	II	22.0	22.0	21.0	18.8	18.8	21.8	21.5	20.5	19.8	18.3	21.3	20.8	19.8	18.5	17.8	21.3	20.8	20.0	18.8	17.8	22.0	21.3	20.5	19.5	19.5	20.2
	III	22.0	20.9	20.1	18.6	18.0	20.0	20.0	19.5	18.6	17.4	17.6	20.3	17.1	17.0	18.0	20.6	19.0	16.1	17.4	17.0	21.5	20.5	19.3	19.3	18.1	19.0
July	I	22.0	21.4	20.2	18.6	17.6	20.6	20.0	19.6	18.6	17.2	18.4	19.4	17.0	16.4	18.4	20.6	19.0	18.4	17.2	16.8	21.0	20.6	19.8	19.2	17.8	19.0
	II	21.4	19.9	18.8	17.3	17.0	19.6	18.8	18.0	17.4	17.4	16.4	15.3	15.8	16.0	15.9	19.0	18.3	16.5	16.9	16.5	19.5	18.3	19.1	18.9	16.9	17.8
	III	20.0	18.3	17.7	17.3	17.0	18.3	17.0	16.7	16.0	16.7	15.7	14.3	13.3	13.7	16.3	19.0	17.0	15.7	14.3	16.3	20.3	19.3	17.7	18.7	16.7	16.9
August	I	22.0	22.0	22.0	22.0	20.2	21.0	20.2	20.2	21.0	20.0	19.2	16.0	15.0	18.0	20.2	20.0	19.2	17.8	18.2	20.0	21.0	20.0	20.0	20.0	20.0	19.8
	II	22.0	22.0	22.0	22.0	20.0	21.0	20.0	22.0	22.0	20.0	19.0	17.0	17.0	19.0	20.0	20.0	20.0	24.0	20.0	21.0	20.0	20.0	20.0	20.0	21.0	20.4
	III	22.0	21.6	21.3	20.0	20.3	21.3	20.9	20.4	19.7	19.3	17.7	17.6	17.7	18.0	19.6	20.3	19.6	26.0	17.9	19.4	21.0	20.7	19.9	19.7	19.4	20.1
October	I	20.5	20.8	20.8	19.8	19.0	19.5	19.8	19.8	20.0	19.0	18.5	18.0	17.3	18.3	18.8	20.0	19.0	19.3	18.8	19.0	20.3	20.0	19.8	19.8	19.3	19.4
	II	20.0	19.0	19.5	18.0	17.0	19.0	19.0	19.0	19.0	17.0	18.0	17.0	17.0	17.5	17.0	20.0	18.5	18.0	18.0	17.0	20.0	20.0	19.0	19.0	17.5	18.4
November	I	9.8	19.5	19.7	19.7	18.0	18.8	18.8	19.0	19.2	17.7	19.0	18.0	17.8	19.2	18.0	19.8	19.5	18.7	19.0	18.2	21.0	20.3	19.5	19.2	18.3	18.6
Average		20.3	20.7	20.3	19.3	18.4	20.1	19.6	19.5	19.2	18.2	18.3	17.6	16.8	17.4	18.2	20.1	19.1	19.3	17.9	18.1	20.7	20.1	19.5	19.4	18.6	19.1

Table 5.22. Changes observed in some physical characteristics (moisture content, test weight and foreign material) of dry edible beans (<u>Phaseolus</u> <u>vulgaris</u>) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Physical Charact.	Location	Storage Period (months)			
		0.0	3.0	5.5	7.5
Moisture content (% w.b.)	A Bottom	14.6	14.3	14.0	13.9
	A Middle	15.2	14.5	14.3	13.8
	A Top	15.3	13.5	12.5	13.7
	A Mean	15.0	14.1	13.6	13.8
	NA Bottom	14.4	14.6	14.6	14.6
	NA Middle	14.4	14.7	14.1	14.5
	NA Top	14.0	14.3	14.0	14.5
	NA Mean	14.2	14.5	14.2	14.5
	Total Mean	14.6	14.3	13.9	14.1
Test weight (kg/m3)	A Bottom	732.5	723.7	736.8	730.1
	A Middle	734.8	728.9	737.7	740.3
	A Top	729.5	734.5	742.7	740.2
	A Mean	732.3	729.0	739.1	736.9
	NA Bottom	739.4	745.0	743.1	730.0
	NA Middle	735.6	719.8	732.1	736.1
	NA Top	735.4	736.7	741.2	730.5
	NA Mean	736.8	733.8	738.8	732.2
	Total Mean	734.5	731.4	739.0	734.5
Foreign material (%)	A Bottom	0.97	1.77	2.63	1.65
	A Middle	0.65	1.23	1.42	1.19
	A Top	0.42	0.75	0.89	1.86
	A Mean	0.68	1.25	1.65	1.57
	NA Bottom	1.04	1.39	0.75	1.59
	NA Middle	1.21	1.14	1.03	1.37
	NA Top	0.58	0.73	1.08	0.79
	NA Mean	0.94	1.09	0.95	1.25
	Total Mean	0.81	1.17	1.30	1.41

Table 5.23. Changes observed in some quality factors (total number of insects per kg., number of live insects per kg. and percentage damaged by insects- *Acanthoscelides obtectus* and *Zabrotes subfasciatus*) of dry edible beans (*Phaseolus vulgaris*) stored during a period of 7.5 months in an aerated (A) and an non-aearated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, Middle and top - within each compartment.

Quality Factor	Location	Storage Period (months)			
		0.0	3.0	5.5	7.5
Total number of insects per kg of beans	A Bottom	7.4	40.2	35.7	67.2
	A Middle	2.5	5.0	27.1	11.0
	A Top	1.2	6.2	6.1	9.8
	A Mean	3.7	17.1	23.0	29.3
	NA Bottom	0.0	2.4	9.8	14.9
	NA Middle	4.9	3.8	6.2	3.7
	NA Top	0.0	6.2	4.9	3.7
	NA Mean	1.6	4.1	7.0	7.5
	Total Mean	2.7	10.6	15.0	18.4
Number of live insects per kg of beans	A Bottom	0.0	0.0	0.0	0.0
	A Middle	0.0	0.0	0.0	0.0
	A Top	0.0	0.0	0.0	1.2
	A Mean	0.0	0.0	0.0	0.4
	NA Bottom	0.0	0.0	0.0	0.0
	NA Middle	0.0	0.0	0.0	0.0
	NA Top	0.0	0.0	0.0	0.0
	NA Mean	0.0	0.0	0.0	0.0
	Total Mean	0.0	0.0	0.0	0.2
Percentage insect damaged beans	A Bottom	1.3	1.3	0.7	1.7
	A Middle	0.0	0.3	0.7	0.0
	A Top	0.0	0.0	1.0	0.3
	A Mean	0.4	0.5	0.8	0.7
	NA Bottom	0.0	0.7	0.0	0.0
	NA Middle	0.0	0.7	0.0	0.0
	NA Top	0.0	0.0	0.0	0.3
	NA Mean	0.0	0.5	0.0	0.1
	Total Mean	0.2	0.5	0.4	0.4

Table 5.24. Changes observed in some damage categories (percent damaged by visible molds or by rodents and sprouted beans) of dry edible beans (*Phaseolus vulgaris*) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage category	Location	Storage period (months)			
		0.0	3.0	5.5	7.5
Visible mold damage (%)	A Bottom	0.3	0.0	0.0	0.3
	A Middle	0.0	0.7	0.3	0.0
	A Top	1.0	0.0	0.3	0.3
	A Mean	0.4	0.2	0.2	0.2
	NA Bottom	1.0	0.0	0.3	0.0
	NA Middle	1.3	0.7	0.3	0.0
	NA Top	2.0	0.0	0.0	0.0
	NA Mean	1.4	0.2	0.2	0.0
	Total Mean	0.9	0.2	0.2	0.1
Rodent Damage (%)	A Bottom	0.3	0.0	0.3	1.0
	A Middle	0.3	0.0	1.3	0.0
	A Top	0.7	1.0	1.0	0.7
	A Mean	0.4	0.3	0.9	0.6
	NA Bottom	0.3	0.3	0.3	0.0
	NA Middle	1.3	0.7	1.0	0.7
	NA Top	0.0	0.7	0.7	0.7
	NA Mean	0.5	0.6	0.7	0.5
	Total Mean	0.5	0.4	0.8	0.5
Sprouted beans (%)	A Bottom	0.0	0.0	0.0	0.0
	A Middle	0.7	0.0	0.0	0.7
	A Top	0.3	0.0	0.0	0.0
	A Mean	0.3	0.0	0.0	0.2
	NA Bottom	0.3	0.3	0.0	0.0
	NA Middle	0.0	0.0	3.0	0.0
	NA Top	0.0	0.0	0.0	0.0
	NA Mean	0.1	0.1	1.0	0.0
	Total Mean	0.2	0.0	0.5	0.1

Table 5.25. Changes observed in some damage categories (percent broken beans, discolored beans or beans with a torn pericarp) of dry edible beans (*Phaseolus vulgaris*) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)			
		0.0	3.0	5.5	7.5
Broken beans (%)	A Bottom	0.7	0.7	1.3	0.0
	A Middle	0.7	1.3	1.3	0.3
	A Top	0.3	0.7	1.3	0.7
	A Mean	0.6	0.9	1.3	0.3
	NA Bottom	1.7	2.0	1.0	1.0
	NA Middle	1.3	1.3	1.0	0.7
	NA Top	1.7	1.3	0.7	0.7
	NA Mean	1.6	1.5	0.9	0.8
	Total Mean	1.1	1.2	1.1	0.6
Discolored beans (%)	A Bottom	4.7	4.7	18.3	21.3
	A Middle	5.0	4.3	16.7	20.0
	A Top	4.0	4.0	21.7	19.3
	A Mean	4.6	4.3	18.9	20.2
	NA Bottom	6.0	3.3	14.3	21.7
	NA Middle	2.0	3.7	16.7	19.0
	NA Top	6.0	4.7	15.0	22.0
	NA Mean	4.7	3.9	15.3	20.9
	Total Mean	4.6	4.1	17.1	20.6
Beans with torn pericarp (%)	A Bottom	1.0	1.7	2.0	0.7
	A Middle	1.7	2.0	1.3	1.3
	A Top	1.0	0.3	1.0	0.3
	A Mean	1.2	1.3	1.4	0.8
	NA Bottom	1.0	0.3	1.0	0.0
	NA Middle	0.3	0.7	1.6	0.3
	NA Top	0.7	0.7	1.0	0.3
	NA Mean	0.7	0.6	1.2	0.2
	Total Mean	0.9	0.9	1.3	0.5

Table 5.26. Changes observed in some damage categories (percent small, wrinkled or dented beans) of dry edible beans (*Phaseolus vulgaris*) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). Observations made at three locations - bottom, middle and top - within each compartment.

Damage Category	Location	Storage Period (months)			
		0.0	3.0	5.5	7.5
Small beans (%)	A Bottom	7.3	10.7	17.0	12.0
	A Center	10.0	8.3	22.3	14.0
	A Top	8.7	9.7	17.3	12.3
	A Mean	8.7	9.6	18.9	12.8
	NA Bottom	8.3	11.0	16.7	13.7
	NA Center	8.0	12.0	19.0	16.0
	NA Top	9.7	11.0	15.0	18.0
	NA Mean	8.7	11.3	16.9	15.9
	Total Mean	8.7	10.4	17.9	14.3
Wrinkled beans (%)	A Bottom	4.7	2.0	6.3	3.3
	A Center	3.0	1.7	3.7	4.0
	A Top	3.7	4.7	6.0	3.3
	A Mean	3.8	2.8	5.3	3.5
	NA Bottom	4.0	2.3	4.0	1.3
	NA Center	4.7	3.7	5.0	2.0
	NA Top	5.0	3.7	4.3	2.7
	NA Mean	4.6	3.2	4.4	2.0
	Total Mean	4.2	3.0	4.9	2.8
Dented beans (%)	A Bottom	2.3	3.3	4.7	1.7
	A Center	0.3	4.3	2.3	3.0
	A Top	3.0	3.0	3.3	3.0
	A Mean	1.9	3.5	3.4	2.6
	NA Bottom	1.3	4.3	3.7	1.3
	NA Center	2.7	3.3	3.0	3.0
	NA Top	0.7	1.0	5.3	3.0
	NA Mean	1.6	2.9	4.0	2.4
	Total Mean	1.7	3.2	3.7	2.5

Table 5.27. Changes observed in some quality indicators (percent beans with storage related damage and beans considered unfit for consumption or planting) of dry edible beans (*Phaseolus vulgaris*) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Quality Indicator	Location	Storage period (months)			
		0.0	3.5	5.5	7.5
Beans with storage related damage (%)	A Bottom	1.9	1.3	1.0	3.0
	A Middle	1.0	1.0	2.3	0.7
	A Top	2.0	1.0	2.3	1.3
	A Mean	1.6	1.1	1.9	1.7
	NA Bottom	1.6	1.3	0.6	0.0
	NA Middle	2.6	2.1	4.3	0.7
	NA Top	2.0	0.7	0.7	1.0
	NA Mean	2.1	1.4	1.9	0.6
	Total Mean	1.9	1.2	1.9	1.1
Beans unfit for consumption (%)	A Bottom	13.7	10.7	15.7	15.0
	A Middle	14.3	11.3	15.7	15.0
	A Top	13.7	10.7	16.7	12.0
	A Mean	13.9	10.9	16.0	14.0
	NA Bottom	14.7	9.0	13.0	10.3
	NA Middle	12.3	10.7	16.0	12.0
	NA Top	15.3	11.0	14.7	13.0
	NA Mean	14.1	10.2	14.6	11.8
	Total Mean	14.0	10.6	15.3	12.9
Beans unfit for planting (%)	A Bottom	17.7	15.3	26.3	24.7
	A Middle	17.3	16.0	30.7	22.3
	A Top	18.3	14.7	30.3	17.0
	A Mean	17.8	15.3	29.1	21.3
	NA Bottom	19.3	14.3	24.0	16.0
	NA Middle	17.3	16.0	29.3	17.3
	NA Top	20.3	15.0	27.7	17.3
	NA Mean	19.0	15.1	27.0	16.9
	Total Mean	18.4	15.2	28.1	19.1

Table 5.28. Changes observed in the mean instrumental hardness, the percentage hard-to-cook beans and the germination rate of dry edible beans (*Phaseolus vulgaris*) stored during a 7.5 month period in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in RUSUMO (low altitude region). The observations are made at three different locations - bottom, middle and top - within each compartment.

Characteristic	Position	Storage period (months)			
		0.0	3.0	5.5	7.5
Mean instrum. hardness (Newton)	A Bottom	3.39	3.58	3.65	3.75
	A Middle	3.34	3.58	3.92	4.13
	A Top	3.84	3.50	3.72	3.81
	A Mean	3.53	3.55	3.76	3.90
	NA Bottom	3.37	3.71	3.93	3.78
	NA Middle	3.59	3.38	3.68	4.09
	NA Top	3.62	3.70	4.06	3.53
	NA Mean	3.53	3.60	3.89	3.80
	Total Mean	3.53	3.58	3.83	3.85
Percent hard-to-cook beans	A Bottom	30.0	29.0	34.0	33.0
	A Middle	33.0	35.0	48.0	45.0
	A Top	46.0	32.0	37.0	35.0
	A Mean	36.3	32.0	39.7	37.7
	NA Bottom	30.0	31.0	40.0	41.0
	NA Middle	33.0	29.0	32.0	47.0
	NA Top	33.0	36.0	56.0	32.0
	NA Mean	32.0	32.0	42.7	40.0
	Total Mean	34.2	32.0	41.2	38.8
Germination rate (%)	A Bottom		87.0	83.5	81.5
	A Middle		84.5	87.5	79.0
	A Top		82.0	91.0	80.5
	A Mean		84.5	87.3	80.3
	NA Bottom		83.0	79.5	76.5
	NA Middle		73.0	79.5	83.5
	NA Top		85.0	69.5	70.5
	NA Mean		80.3	76.2	76.8
	Total Mean		82.4	81.8	78.6

February 4, 1987 (13.5 months). Both compartments were fumigated at the beginning of storage and again on December 9, 1986.

The generator which powered the aeration fan was stolen on September 15, 1986 and was not replaced. Therefore, there was no aeration after that date. The aeration system differed from aeration systems at Kanama, Rusatira and Rusumo in several respects. First, airflow was upward through the product at Gikoro rather than downward as in the other three locations. A different fan was used than at the other three locations and the duct (pipe) delivering air to the plenum was somewhat smaller. The different fan and smaller air delivery duct in conjunction with sorghum which has a much higher resistance to airflow than beans resulted in a total airflow of 0.9 m^3/min (32 cfm) which was about one-third that at the other three locations. This potentially reduced the effectiveness of aeration.

The average ambient minimum and maximum temperatures (Table 5.1) during the test were 17.6 and 25.1°C, respectively. The temperatures were quite uniform in the non-aerated compartment (NAC) (Table 5.29). Temperatures were also quite uniform in the aerated compartment (AC) (Table 5.30) and were approximately the same as in the NAC through August 1986. In September-November 1986 some of the readings in the AC (e.g.,. T30, T35, T39, T40, T49, T50 in Table 5.30) started to increase indicating insect activity. This was after the generator had been stolen and so aeration could not be used to control the temperatures. However, the temperature information was useful in identifying development of a problem. The fumigation on December 9, 1986 was undertaken in response to this information.

The moisture content changed little in either the NAC or the AC (Table 5.31). The 0.9 percentage point increase in moisture content at the top of the AC between the 8 and 13.5 month samplings is probably a result of the insect activity observed in that area. Test weight did not change significantly.

The number of insects (Sitophilus) per kg of grain (Table 5.32) increased dramatically between the 8 and 13.5 month samplings in the AC. This is consistent with the problems identified in that period. The fumigation was effective in killing all of the Sitophilus. Live insects (Rhyzopertha dominica) (Table 5.33) were found at the 2.5 month sampling; however, no live insects were found after that.

5.2. Comments on Silo Design and Management

It is fair to state that the design of the cooperative silos is sound in principle. Provided the construction was properly executed, the building itself is not the cause of the sometimes catastrophic situations of grain spoilage. The main problem is lack of management and supervision.

Table 5.29. Ten-day mean temperatures (°C) in the non-aerated compartment of grain sorghum at the cooperative silo at GIKORO (December 1985 - November 1986). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	AVE
December	I	21.3	20.7	20.0	20.0	20.7	21.7	20.7	20.3	20.3	21.3	21.3	21.7	21.7	21.0	21.3	21.7	22.0	22.0	21.7	22.0	21.7	21.7	21.7	21.7	21.3	21.3
	II	21.4	21.0	20.4	20.4	20.9	21.4	20.8	20.3	20.3	21.0	21.8	21.8	21.8	21.3	21.6	21.8	22.0	21.9	21.8	21.9	21.8	21.8	21.8	21.8	21.8	21.4
January	I	21.3	20.9	20.1	20.1	20.6	21.6	20.6	20.3	20.0	20.6	21.8	21.9	21.8	21.5	21.6	21.8	22.0	22.0	21.9	21.8	21.6	21.9	21.9	21.8	21.8	21.3
	II	22.0	21.5	21.4	21.4	21.6	22.1	21.4	21.4	21.3	22.1	21.9	22.0	21.8	21.8	22.4	21.8	22.0	21.9	22.0	22.4	21.8	22.0	21.9	22.0	22.4	21.9
	III	22.1	21.4	21.1	21.1	21.3	22.1	21.4	21.3	21.3	21.4	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.3	22.0	22.0	22.0	22.0	22.1	21.8
February	I	21.6	21.0	20.7	20.7	20.7	21.6	20.7	20.6	20.6	20.6	21.9	22.0	22.0	22.0	21.7	22.0	22.0	22.0	22.0	21.7	21.9	22.0	22.0	22.0	22.0	21.5
	III	21.7	21.0	20.7	20.5	21.5	22.3	21.5	21.5	21.3	21.8	22.0	22.0	22.0	22.0	22.2	21.8	21.8	21.8	22.0	22.2	21.8	22.0	22.0	22.0	22.2	21.7
March	I	21.3	20.5	20.3	20.3	20.6	21.5	20.8	20.4	20.3	20.8	22.0	22.0	22.0	22.0	21.6	21.6	21.9	21.9	21.9	21.8	21.9	22.0	22.0	22.0	22.0	21.4
	II	20.2	20.0	19.4	19.4	19.6	21.0	20.2	20.0	20.0	19.2	22.0	22.0	22.0	22.0	21.2	22.0	22.0	22.0	22.0	21.4	22.0	22.0	22.0	22.0	22.0	21.1
	III	20.4	20.1	19.6	19.7	20.4	21.3	20.4	20.4	20.4	20.9	21.9	22.0	22.0	21.9	21.4	21.9	21.9	21.9	21.9	21.3	21.9	22.0	22.0	22.0	21.9	21.3
April	I	20.0	20.0	19.8	19.8	19.8	20.5	19.7	19.7	19.7	19.7	21.7	21.8	21.8	21.5	20.7	21.5	21.8	21.8	21.7	21.2	21.8	21.8	21.8	21.8	21.7	20.9
	II	20.0	19.3	19.0	19.0	19.2	20.0	19.0	19.0	19.0	19.0	21.0	21.3	21.0	21.0	20.0	21.0	21.5	21.3	20.7	20.7	21.5	21.8	21.5	21.2	21.0	20.4
	III	20.0	19.4	19.1	19.2	19.6	19.9	19.1	19.1	19.1	19.6	21.0	21.2	21.0	20.8	20.4	21.2	21.4	21.4	20.8	21.0	21.4	21.7	21.8	21.2	21.0	20.5
May	I	20.0	19.7	19.5	19.7	19.8	20.0	19.5	19.2	19.2	19.8	20.7	21.0	21.0	21.0	20.8	21.0	21.3	21.5	21.3	21.3	21.2	21.7	21.7	21.5	21.0	20.6
	II	20.2	20.0	20.0	20.0	20.0	20.0	19.8	19.3	19.7	20.0	21.0	21.0	21.0	20.5	20.8	21.0	21.2	21.2	21.0	21.0	21.2	21.5	21.3	21.0	21.0	20.6
	III	19.9	19.3	19.1	19.1	19.1	19.8	19.1	19.0	18.9	19.3	20.9	21.0	20.9	21.0	20.0	21.0	21.1	21.0	21.0	20.4	21.0	21.0	21.0	21.0	20.8	20.2
June	I	20.0	20.0	19.9	19.7	20.0	20.0	19.4	19.1	19.1	19.9	21.0	21.0	20.7	20.6	20.3	21.0	21.0	21.0	21.1	21.0	21.0	21.0	21.0	20.9	20.7	20.4
	II	20.3	20.0	19.7	19.7	19.8	20.3	19.7	19.5	19.5	19.5	21.0	21.0	21.0	20.7	20.3	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.5
	III	21.0	21.0	21.0	20.8	21.0	21.0	20.4	20.0	20.2	20.4	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.2	21.2	21.0	21.0	21.0	21.0	21.0	20.9
July	I	21.0	20.4	20.0	20.0	20.0	20.8	20.0	20.0	20.0	20.0	21.0	21.0	21.0	21.0	20.8	20.8	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	20.7
	II	21.8	21.0	20.8	20.8	21.0	21.8	20.8	20.2	20.0	20.8	21.0	21.0	21.0	21.0	21.0	20.8	21.0	21.0	21.0	21.8	21.0	21.0	21.0	21.0	21.0	21.0
	III	22.0	21.0	21.0	20.8	20.8	21.0	20.0	20.0	20.0	20.0	21.0	21.2	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.2	21.0	21.0	21.0	21.2	21.0	20.9
August	I	21.0	20.2	20.2	20.2	20.2	20.2	20.0	19.6	19.6	19.8	21.0	21.0	21.0	21.0	20.4	21.0	21.0	21.0	20.5	21.0	21.0	21.0	21.0	21.0	21.0	20.6
	II	22.2	21.8	21.8	21.8	22.0	22.0	21.2	21.2	21.4	22.0	21.4	21.8	21.2	21.2	22.2	21.0	21.2	21.2	0.0	22.0	21.2	21.4	21.2	21.4	0.0	19.8
	III	23.0	22.7	22.5	22.5	22.8	22.5	22.0	22.0	22.0	22.8	22.0	22.0	21.8	22.0	23.0	21.8	21.8	22.0	0.0	22.8	22.2	22.0	22.0	22.0	0.0	20.5
September	I	22.4	22.1	21.9	21.9	22.0	21.6	21.4	21.0	21.1	21.1	22.0	22.0	22.0	22.0	22.3	22.0	22.0	22.0	22.5	22.3	22.0	22.0	22.0	22.4	22.0	21.9
	II	22.0	21.6	21.4	21.4	21.7	21.6	21.4	21.0	21.0	21.6	22.0	22.0	22.0	22.0	22.3	22.0	22.0	22.0	22.0	19.7	22.0	22.0	22.0	22.0	22.3	21.7
	III	22.2	22.0	21.8	21.8	22.2	22.2	21.5	21.5	21.5	21.8	22.0	22.0	22.0	22.3	22.2	22.0	22.0	22.0	22.3	22.8	22.0	22.2	22.2	22.5	22.8	22.1
October	I	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.4	22.9	22.1	22.6	22.3	22.9	23.3	22.1	22.3	22.9	23.0	23.4	22.1	23.0	23.0	23.0	23.4	22.6
	II	22.0	21.6	22.0	21.6	21.6	21.8	21.6	21.3	21.4	21.4	22.5	22.9	22.8	23.1	22.6	22.6	22.9	23.1	23.1	23.1	22.9	23.1	23.8	23.3	23.4	22.5
	III	22.2	21.8	21.6	21.6	21.8	22.6	21.8	21.6	21.6	21.9	22.9	23.0	23.0	23.0	22.8	23.0	23.0	23.0	23.2	23.6	23.0	23.1	23.4	23.3	23.3	22.6
November	I	22.4	22.3	22.3	22.4	20.2	20.9	20.2	20.0	20.0	23.0	23.0	23.0	23.0	23.0	21.9	23.0	23.0	23.2	24.0	23.0	23.2	24.0	20.1	-	23.0	21.4
	II	21.3	21.0	21.0	21.0	20.0	21.0	20.0	20.0	20.0	21.5	22.3	23.0	22.8	22.7	21.8	22.8	23.0	23.8	24.0	24.0	24.0	24.0	21.2	-	23.0	21.2
	III	20.0	20.0	20.0	20.0	20.0	20.8	20.0	20.0	20.0	20.0	22.0	23.0	22.8	22.0	22.0	23.0	23.2	23.8	24.0	23.8	23.8	24.0	21.6	-	23.8	20.9
Average		21.3	20.8	20.6	20.6	20.7	21.2	20.5	20.4	20.4	20.8	21.7	21.8	21.7	21.6	21.5	21.7	21.8	21.9	20.6	21.9	21.8	22.0	21.7	21.7	20.6	21.3

Table 5.30. Ten-day mean temperatures (°C) in the aerated compartment of grain sorghum at the cooperative silo at GIKORO (December 1985 - November 1986). Thermocouple locations defined in Fig. 5.1. (I,II and III - first, second and third 10-day period, respectively.)

		T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36	T37	T38	T39	T40	T41	T42	T43	T44	T45	T46	T47	T48	T49	T50	AVE
December	I	20.7	21.0	20.7	21.0	21.3	21.7	21.7	21.7	21.3	21.3	22.0	22.7	22.7	21.7	21.3	19.7	21.3	21.3	21.3	-	21.0	21.7	21.3	21.3	21.3	21.3
	III	21.0	21.4	21.1	20.9	20.9	21.6	21.9	21.6	21.0	20.9	21.9	22.0	22.1	21.4	21.0	19.0	20.5	21.8	20.9	-	21.1	21.9	21.9	21.4	21.1	21.2
January	I	20.4	20.6	20.9	20.5	20.5	21.0	21.0	21.0	20.5	20.5	21.5	22.0	21.9	20.8	20.5	18.5	19.9	21.1	20.5	-	20.6	21.1	21.0	20.8	20.5	20.6
	II	21.4	21.6	21.5	22.4	22.3	21.3	21.6	21.5	22.3	22.3	21.4	21.5	21.5	22.1	22.0	20.9	21.8	21.9	21.8	-	21.6	21.9	21.9	22.4	22.3	21.8
	III	21.5	21.8	21.9	21.0	20.9	21.3	21.3	21.3	21.0	21.0	21.5	21.6	21.4	21.4	20.9	20.4	21.5	22.0	21.0	-	21.9	22.0	21.9	21.1	20.9	21.3
February	I	21.0	21.4	21.6	20.7	20.7	21.0	21.3	21.0	20.3	20.6	21.4	21.6	21.4	20.9	20.4	19.0	21.0	21.7	21.0	-	21.4	21.7	22.0	21.4	20.9	21.0
	III	19.7	20.7	21.2	21.3	21.2	20.8	20.8	21.0	21.0	21.0	20.8	20.8	20.8	21.0	20.8	18.8	18.5	20.7	21.2	-	20.0	21.0	21.5	21.5	21.7	20.7
March	I	20.6	20.4	20.6	20.5	21.0	20.8	20.9	20.9	20.9	21.3	20.9	20.9	20.9	20.9	21.1	19.3	19.8	20.6	20.5	-	20.9	20.9	21.4	21.0	21.1	20.6
	II	20.4	20.8	20.8	20.4	20.4	20.8	21.0	21.0	20.8	20.4	21.0	21.2	21.2	21.0	20.8	20.0	20.6	21.2	20.4	-	21.0	21.4	22.0	21.4	21.2	20.8
	III	20.3	20.6	20.9	20.9	21.0	20.7	20.9	20.9	21.0	21.0	20.9	20.9	21.0	21.1	21.1	18.9	20.4	20.7	21.1	-	21.0	21.0	21.1	21.1	21.3	20.8
April	I	20.7	21.5	21.3	21.2	21.0	21.0	21.3	21.2	21.0	21.0	21.0	21.5	21.3	21.0	20.7	20.0	20.5	21.7	21.7	-	21.5	21.7	22.0	21.7	21.2	21.0
	II	20.7	21.3	21.3	21.2	21.3	21.0	21.3	21.5	21.0	21.0	21.0	21.5	21.7	21.2	20.8	20.0	20.2	21.5	22.0	-	21.0	21.8	22.0	22.0	22.0	21.1
	III	20.7	21.2	21.4	21.3	21.4	20.9	21.1	21.1	21.1	21.0	21.0	21.0	21.3	21.2	21.1	20.3	20.7	21.3	22.0	-	21.0	21.7	22.0	22.0	22.0	21.1
May	I	20.7	21.0	21.0	21.0	21.5	20.8	21.0	21.0	21.0	21.2	21.0	21.0	21.3	21.2	21.2	19.7	20.7	21.7	21.7	-	20.5	21.8	21.8	21.8	21.8	21.1
	II	20.2	20.8	21.0	21.0	21.0	21.2	21.0	21.0	21.0	21.3	21.0	21.0	21.0	21.0	21.0	20.2	21.0	21.8	22.0	-	21.0	21.7	22.0	22.0	22.0	21.1
	III	20.0	20.0	20.1	20.3	20.4	20.1	20.3	20.5	20.3	20.6	21.0	21.0	21.0	20.9	20.3	20.1	21.2	21.8	22.0	-	21.0	21.3	21.7	21.6	21.0	20.6
June	I	20.0	20.0	20.1	20.1	21.0	20.1	20.1	20.4	20.9	21.0	20.9	20.9	21.0	21.0	21.0	20.1	21.3	21.9	21.7	-	21.0	21.1	21.1	21.1	21.6	20.7
	II	20.0	20.0	20.0	20.5	21.0	20.0	20.8	21.0	21.0	21.7	21.0	21.0	21.0	21.2	21.3	20.0	21.0	21.5	21.3	-	20.8	21.2	21.2	21.0	21.7	20.7
	III	18.4	19.4	20.4	21.0	21.0	20.2	21.0	21.0	21.0	22.0	20.4	21.0	21.2	21.6	21.8	18.2	17.4	18.6	20.8	-	18.8	19.2	20.4	21.4	22.0	20.2
July	I	18.4	18.0	19.0	20.0	21.0	20.0	20.0	20.2	21.0	22.0	20.0	20.0	20.4	21.2	21.6	18.2	16.6	17.6	19.2	-	18.4	17.4	18.4	19.8	21.0	19.5
	II	18.8	18.8	19.4	20.0	21.0	20.0	20.0	20.4	21.0	22.0	20.2	20.2	20.0	20.8	21.6	20.2	18.4	18.0	17.8	-	20.2	18.8	18.6	19.2	20.8	19.8
	III	19.4	19.8	20.0	20.4	21.2	20.4	20.4	20.8	21.4	21.6	20.6	20.6	21.0	21.4	21.2	19.0	18.4	18.6	19.2	-	20.0	19.4	19.6	20.2	21.0	20.1
August	I	20.2	20.0	20.0	20.0	21.0	21.0	21.0	21.0	21.0	21.2	21.0	21.0	21.0	21.0	21.2	20.2	20.0	20.0	20.2	-	20.0	20.0	20.0	20.4	21.0	20.5
	II	20.2	20.4	21.0	21.8	22.0	21.2	21.2	21.6	22.0	22.4	21.2	21.2	21.6	21.8	22.4	20.0	18.8	19.2	20.0	-	20.4	19.4	20.4	21.0	22.0	21.0
	III	20.8	20.5	21.7	22.0	22.8	22.0	22.0	22.2	23.0	23.2	21.5	21.7	22.0	22.5	23.7	20.7	18.5	18.7	20.7	-	20.2	19.7	20.0	21.3	22.7	21.4
September	I	21.0	21.0	21.4	22.0	22.4	22.0	22.0	22.0	22.4	22.7	22.0	22.0	22.0	22.6	22.7	21.0	19.4	19.9	21.0	-	21.0	20.4	21.0	21.6	22.7	21.5
	II	21.0	21.0	21.3	22.0	22.1	22.0	22.0	22.0	22.0	22.6	22.0	22.0	22.0	22.0	22.7	20.3	19.9	20.0	21.0	-	21.0	21.0	21.1	22.1	22.9	21.5
	III	21.3	21.5	21.8	22.0	22.8	22.0	22.0	22.2	22.5	23.0	22.0	22.0	22.0	22.5	23.5	20.8	20.2	20.8	21.5	-	21.3	21.2	21.7	22.0	23.8	22.0
October	I	22.6	22.4	22.4	22.4	23.3	22.4	22.6	23.0	23.7	23.9	22.3	22.4	22.6	23.0	24.4	21.6	21.1	21.0	22.0	-	22.0	22.0	22.0	22.5	24.6	22.5
	II	21.8	22.0	22.0	22.4	24.0	22.1	22.5	23.1	23.4	23.9	22.9	23.1	23.1	23.5	24.1	22.0	21.5	21.8	22.3	-	22.1	22.1	22.3	23.1	25.5	22.7
	III	22.0	21.9	22.0	22.4	25.0	22.2	22.6	22.9	23.0	25.0	23.0	23.0	23.0	24.0	26.1	22.1	22.0	22.0	23.0	-	22.2	22.8	23.0	23.9	29.0	23.1
November	I	21.1	21.0	21.0	22.0	26.0	22.0	22.0	22.1	23.1	26.0	23.0	23.0	23.0	24.0	27.9	22.0	22.0	22.7	23.9	-	22.9	23.0	23.1	24.6	32.4	23.1
	II	21.0	21.0	21.0	22.2	27.8	21.7	21.7	22.9	23.0	27.8	22.7	23.0	23.0	24.5	29.7	22.0	22.0	23.0	24.3	-	23.0	23.2	23.2	25.3	33.0	23.4
	III	21.0	21.0	21.2	23.5	31.5	21.0	21.3	21.7	24.0	31.3	22.2	22.8	22.7	26.2	32.8	22.2	22.2	23.2	25.5	-	23.0	23.0	24.0	26.2	33.0	23.9
Average		20.6	20.8	21.0	21.2	22.2	21.1	21.3	21.4	21.6	22.3	21.4	21.6	21.6	21.9	22.5	20.2	20.3	20.9	21.4	-	21.0	21.2	21.4	21.8	23.0	21.3

Table 5.31. Changes observed in some physical characteristics (moisture content, test weight and foreign material) of grain sorghum stored during 13.5 months in an aerated (A) and a non-aerated (NA) compartment of the cooperative silo in GIKORO (medium altitude region). Observations made in three layers (bottom, middle, top) within each compartment.

Physical Charact.	Location	Storage Period (months)				
		0.0	2.5	6.0	8.0	13.5
Moisture Content (%)	A Bottom		12.1	12.9	12.6	13.0
	A Middle	12.3		12.1	12.3	12.7
	A Top		12.9	12.8	12.5	13.4
	A Mean	12.3	12.5	12.6	12.5	13.0
	NA Bottom		11.9	11.5	11.6	11.8
	NA Middle	11.1		11.3	11.2	11.6
	NA Top		11.8	11.8	12.0	12.0
	NA Mean	11.1	11.9	11.5	11.6	11.8
	Total Mean	11.7	12.2	12.1	12.0	12.4
Test Weight (kg/m^3)	A Bottom		641.8	641.3	641.2	639.9
	A Middle	640.0		644.9	641.7	643.0
	A Top		637.8	631.3	629.7	605.3
	A Mean	640.0	639.8	639.2	637.5	629.4
	NA Bottom		638.6	655.6	651.9	653.5
	NA Middle	648.0		645.7	648.9	647.3
	NA Top		643.9	640.2	638.8	642.0
	NA Mean	648.0	641.3	647.2	646.5	647.6
	Total Mean	644.0	640.5	643.2	642.0	638.5
Foreign Material (%)	A Bottom		1.07	1.35	1.06	1.21
	A Middle	0.60		2.34	1.74	1.33
	A Top		1.21	1.05	2.06	1.58
	A Mean	0.60	1.14	1.58	1.62	1.37
	NA Bottom		1.01	2.11	1.32	1.60
	NA Middle	0.55		2.43	2.49	1.84
	NA Top		2.00	1.48	.59	1.07
	NA Mean	0.55	1.50	2.01	1.47	1.50
	Total Mean	0.57	1.32	1.79	1.54	1.44

Table 5.32. Changes observed in the population of *Sitophilus spp.* (total number of insects per kg. of grain, number of live insects per kg. of grain) in grain sorghum stored during 13.5 months in an aerated (A) and non-areated (NA) compartment of the cooperative silo in GIKORO (medium altitude region). Observations made in three layers (bottom, middle, top) within each compartment.

Population Charact.	Location	Storage Period (months)				
		0.0	2.5	6.0	8.0	13.5
Total number of insects per kg of grain	A Bottom		5.7	1.4	0.0	88.0
	A Middle	24.1		0.0	5.7	7.1
	A Top		5.7	15.8	27.4	1498.6
	A Mean	24.1	5.7	5.7	11.0	531.2
	NA Bottom		4.3	0.0	2.8	0.0
	NA Middle	9.8		0.0	0.0	11.2
	NA Top		7.1	1.4	0.0	11.3
	NA Mean	9.8	5.7	0.5	0.9	7.5
	Total Mean	17.0	5.7	3.1	6.0	269.4
Number of live insects per kg of grain	A Bottom		0.0	0.0	0.0	0.0
	A Middle	0.0		0.0	0.0	0.0
	A Top		0.0	0.0	0.0	0.0
	A Mean	0.0	0.0	0.0	0.0	0.0
	NA Bottom		0.0	0.0	0.0	0.0
	NA Middle	0.0		0.0	0.0	0.0
	NA Top		0.0	0.0	0.0	0.0
	NA Mean	0.0	0.0	0.0	0.0	0.0
	Total Mean	0.0	0.0	0.0	0.0	0.0

Table 5.33. Changes observed in the population of *Rhyzopertha dominica* (total number of insects per kg. of grain, number of live insects per kg. of grain) in grain sorghum stored during 13.5 months in an aerated (A) and non-aerated (NA) compartment of the cooperative silo in GIKORO (medium altitude region). Observations made in three layers (bottom, middle, top) within each compartment.

Physical Charact.	Location	Storage Period (months)				
		0.0	2.5	6.0	8.0	13.5
Total number of insects per kg. of grain	A Bottom		1.4	0.0	0.0	0.0
	A Center	0.0		0.0	1.4	0.0
	A Top		0.0	12.9	0.0	0.0
	NA Mean	0.0	0.7	4.3	0.5	0.0
	NA Bottom		0.0	0.0	0.0	4.2
	NA Center	0.0		0.0	0.0	0.0
	NA Top		2.8	1.4	0.0	0.0
	NA Mean	0.0	1.4	0.5	0.0	1.4
	Total Mean	0.0	1.1	2.4	0.2	0.7
Number of live insects per kg. of grain	A Bottom		1.4	0.0	0.0	0.0
	A Center	0.0		0.0	0.0	0.0
	A Top		0.0	0.0	0.0	0.0
	A Mean	0.0	0.7	0.0	0.0	0.0
	NA Bottom		0.0	0.0	0.0	0.0
	NA Middle	0.0		0.0	0.0	0.0
	NA Top		2.8	0.0	0.0	0.0
	NA Mean	0.0	1.4	0.0	0.0	0.0
	Total Mean	0.0	1.0	0.0	0.0	0.0

However, in a number of problem cases encountered it was clear that moisture migration into the building was the initiating cause of spoilage. Moisture can enter a compartment either through the floor or through the walls. Moisture migration through the floor can be traced back to faulty installation of the moisture barrier during the construction or a breakdown of the moisture barrier after proper installation (age, earthquake, small holes, ...). In this case no lasting or efficient solution exists. When the moisture penetration occurs through the walls, it is usually a case where rain water hits directly on an outside wall. In this case it usually suffices to extend the roof construction so that the outside walls are no longer moistened by rainwater.

It should be mentioned that a number of these moisture problems are enhanced or even caused by a poor site selection. Silos should only be constructed on well-drained sites that are well protected against run-off. Silos usually have concrete gutters constructed around them, but they are often in poor shape (cracked, etc.). It is better to avoid sites where water can collect near the silo. Too often easy access or convenience seems to determine the site selection.

The management problem is enhanced by the lack of an easy access to the stored product for inspection. The loading hatch is the only opening through which a probe can be inserted, but only a minor portion of the silo can be reached in this way. It proved virtually impossible to sample through the emptying spout. Before any grain inspection program can ever become successful, it is imperative that access to the stocks be improved by modifying the present silo construction in some way.

One proposed modification, now being tested, consists of incorporating sampling ports in the ceiling of the compartments. Four sampling ports were installed in the ceiling of one of the compartments at the cooperative silo in Gikoro. They were located near the three corners away from the hatch and in the center of the ceiling (Fig. 5.3). They consist of a short piece of internally threaded pipe (10 cm (4") in diameter) and are vertically installed in the compartment ceiling. The ports can be closed with a threaded plug and a padlock. Through these ports a grain thermometer or a sampling probe can easily be inserted into the grain mass.

Also the problem of emptying the silos has been studied. The present system (raking out the grain through the narrow and horizontal emptying spout) is very time consuming and tiring. For cooperatives that would like to increase their turnover rate this emptying operation is a real bottleneck. Two possible solutions were considered: 1) changing the emptying spout from a horizontal to an inclined position to obtain a free flow of grain and 2) developing a hand driven, mechanical (auger type) emptying device. A horizontal spout has the appreciable advantage that the grain flow is interrupted when the grain is not stirred (e.g., when

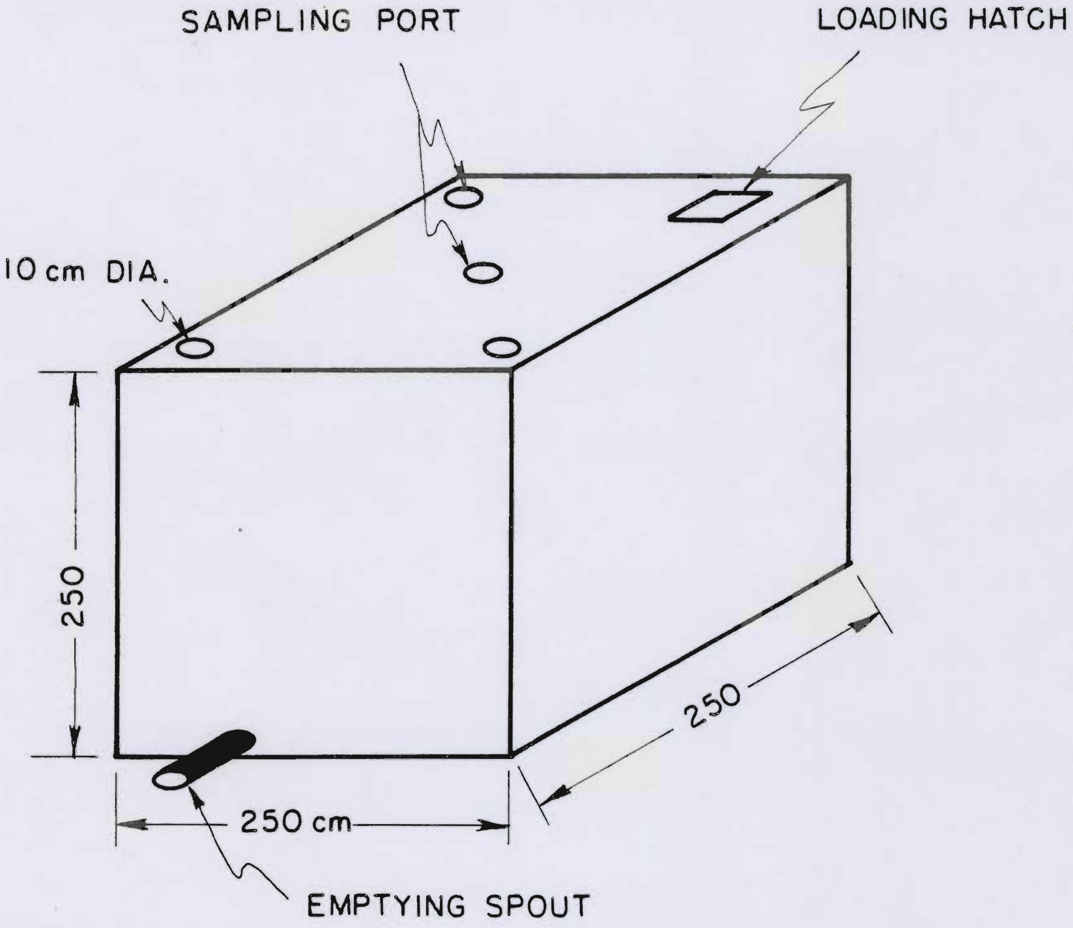


Figure 5.3. Diagram of sampling ports installed in the cooperative silo at GIKORO.

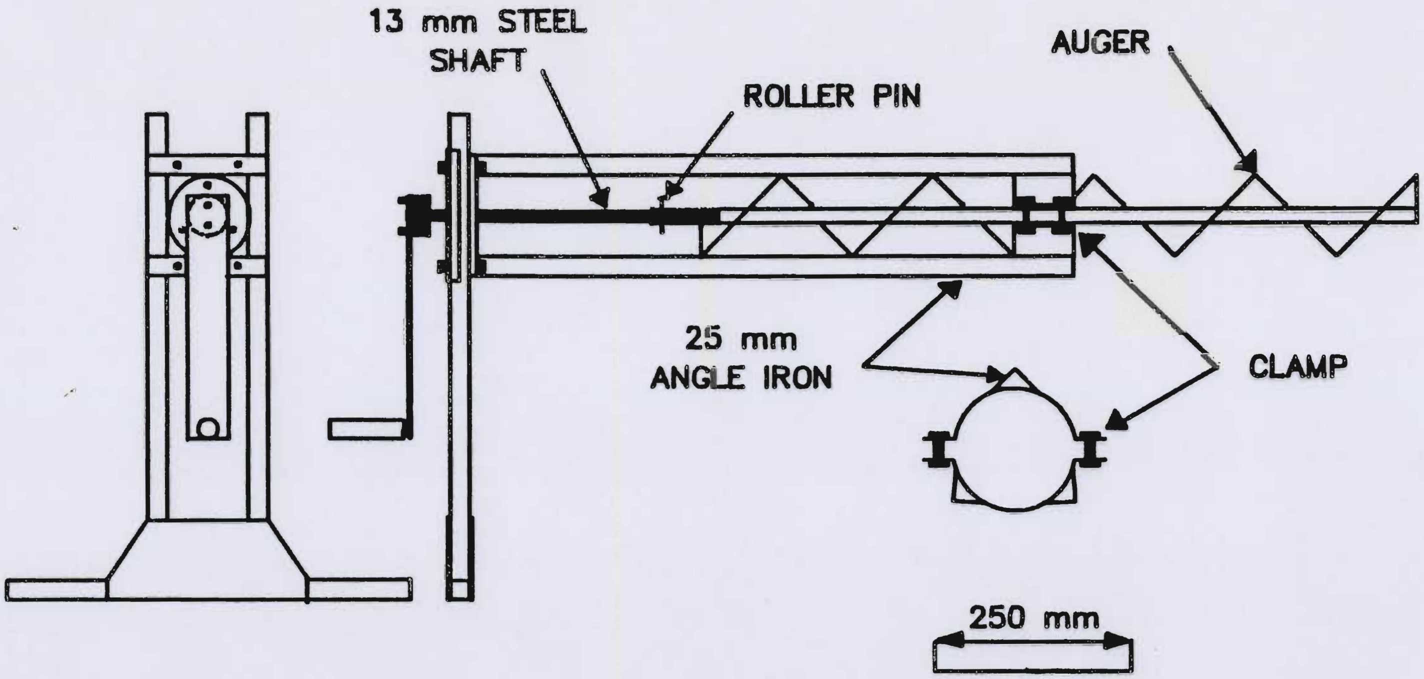


Figure 5.4. Diagram of the hand operated auger unloading system for cooperative silos.

laborers interrupt the emptying operation to change bags or when the spout is left open and unattended), so it was decided to select the second solution.

A prototype emptying device was designed and fabricated at the Agricultural Engineering Department of the University of Minnesota (Fig. 5.4). It consists essentially of an auger and a handle. A bearing embracing the auger shaft is mounted on a metal frame that can be clamped on the emptying spout. The clamps and an adjustable support hold the frame and the auger in place during operation. A preliminary field test (in which both methods were compared) showed that a crew of 2 persons can remove 1370 kg of sorghum from the silo per hour. The auger is operated at 75 RPM and each turn removes about 330 grams of sorghum. From these and other observations, it was extrapolated that a crew could empty about 6-8 tons of sorghum per day this way, including the work performed by the crew to adjust the weight of the bags to a standard weight and transport the bags to a temporary storage area. This result is basically double that of the conventional daily sorghum handling capacity of the cooperative. The laborers said the work was considerably less tiring than the traditional method. The force required to turn the handle is very small. Modifying the device to increase its capacity (by including a chain and sprocket assembly or by shortening the handle) seems possible. Further testing in both sorghum and beans is needed before a final evaluation can be made.

To date electrical power is not available at most silos. Several serious power-related problems were encountered during the execution of these experiments. The generator in Rusatira broke down beyond repair and the generator in Gikoro was stolen and never recovered. For individual silos it is practically impossible to power an aeration system with portable generators. The breakdowns are frequent and the fuel and maintenance bills are extremely high.

5.3. Summary and Conclusions

Well-constructed, well-managed cooperative silos provide good storage conditions. Problems that have been observed have been associated with poor construction including poor site selection which ignored proper drainage. Poor management resulting from the rapid turnover and inadequate training of silo managers was also observed to be a problem.

Experiments involving monitoring of temperatures in non-aerated and aerated silos showed that the silos provide good thermal protection for the stored product. The result is that there is little advantage for aeration in these relatively small compartments.

The design of the silo compartments makes it difficult to monitor the product during storage. Modifications in silo compartments to facilitate monitoring are currently under evaluation. These modifications along with improved procedures for monitoring (Appendix A) should lead to improvements in management of beans and sorghum during storage.

Unloading of the silos has also been a problem. A manually operated auger system shows promise for improving unloading of silo compartments.

Hanger storages at the cooperative level are suitable for storage in bags on pallets (Section 2.2.1). However, they are not suitable for storage in bulk due to poor vapor barriers in floors and walls.

Although hangars are less expensive than silos and offer more flexibility in use, they provide less natural protection against rodents and greater risks with fumigation for insect control. Monitoring grain quality is critical as with other structures. If storage size is kept relatively small (<20 MT), satisfactory representative sampling is feasible with some ingenuity and effort.

6. PRODUCER STORAGE LEVEL EXPERIMENTS

6.1. Introduction

Based on the findings of the storage survey (Dunkel et al., 1986) a collection was made of traditional storage containers from different local markets. These included small, medium, large and very large baskets, and clay pots. A traditional exterior granary and the 'imboho,' a storage container still used in some areas of Rwanda, were also included. Two alternative containers that could potentially achieve airtight storage conditions were also included. These were a metal oil drum and a plastic container that could be sealed.

The four types of baskets were locally made from split bamboo or reeds woven together with all spaces (openings) covered with a cow dung/mud mixture. The baskets ranged in size from 20 to 400 kg capacity. They are generally cylindrical in shape with the middle area slightly bulging, i.e. larger in diameter than the lower and upper portions. Bamboo and reeds are tied together with dried grass or woody vines (no string or nails). The very large basket was made in the Gitarama area. The others were purchased in the market at Base (Ruhengeri Prefecture).

The exterior granaries have a capacity of 1000 kg and were built by a team of male artisans living in the vicinity of OPROVIA's headquarters at Kicukiro. These are large bowl-shaped structures made entirely from wood timber, reeds and bamboo tied together with woody vines and lined like the baskets with cow dung. They are elevated off the ground about 50-75 cm and rest on a small platform. The granaries are covered with a thick, thatch (dried grass) conical roof which extends well beyond the rim of the storage area. The roofs are slanted somewhat to allow an opening on one side, away from the prevailing wind and rain, for loading and emptying.

The clay pots, purchased at Base, were hand-made from wet clay, without use of a potter's wheel, and then baked in an open fire. They are roughly spherical in form: 50 cm in diameter at the mid-section, 65 cm in height, and with a 25-cm flask-shaped opening at the top. The capacity of each pot is approximately 50 kg.

The imbohos, traditional transportation and storage receptacles, were constructed by farmers in the Kibungo region as described by Dunkel et al. (1986). Dried banana sheaths tied together with vine around a long pole are the primary materials and envelop the beans which are inserted as the imboho is assembled. The imbohos used in these experiments had a capacity of 50 to 70 kg.

The metal drums were second-hand 200 liter (capacity: 150 kg) oil drums purchased in the Kigali market and cleaned with boiling water and solvents. The metal lids were intact and contained a small diameter opening with a screw-type metal plug.

The plastic drums (barrels), like the oil drums, are imported containers and were purchased used (second-hand) in the Kigali market where they are usually sold for use in transporting banana beer. Shorter and smaller than the metal drums, they have about half the capacity (75-80 kg). They are constructed of thick, dark blue plastic and are covered with a plastic lid that is sealed to the drum with a metal rim tightened with a screw.

6.2. Methodology.

The original plan was to place beans at three moisture contents--11, 13 and 16%--in each of the storage containers with three replications. There were not enough storage containers available of some types to include three replicates at all moisture contents. In addition it was difficult to obtain beans of appropriate moisture content which affected some of the experiments.

The experiments were conducted at the site of the OPROVIA headquarters in Kicukiro. All containers except the exterior granaries were placed in a storeroom attached to one of the large warehouses. The exterior granaries were constructed near the OPROVIA Administrative Building.

Beans were put into containers starting in February 1986. Beans arrived slowly at the warehouse. The initial lot of beans was too dry to use in the 16% experiments but was dried in a heated air dryer (Edmister et al., 1986) to reach the 13 and 11% moisture levels needed for the test. Higher moisture content beans purchased together with beans for experiments at the cooperative storages were used for tests targeted at 16% initial moisture content. These beans were put into storages at approximately 16.5% moisture content in early March 1986.

Beans put into the airtight containers (metal and plastic drums) were not treated for insects. Beans put into all of the other containers were mixed with the insecticidal dust, Actellic (1% pirimiphos-methyl), at the recommended rate.

A limited amount of sampling and analysis was done at the beginning of the tests. Initial estimates of moisture content, instrumental hardness, and percent hard-to-cook were available. Complete samplings were made on June 27, 1986 (II) and February 3, 1987 (IV). Another sampling was done on October 30, 1986 (III); however, because some of the traditional containers had been covered with a layer of leaves and cow dung or dried clay prior to that date, they could not be sampled.

6.3. Results and Discussion

The results are presented in nine tables. The results for the small, medium and large baskets are grouped in Tables 6.1, 6.2 and 6.3 The results for the clay pots, imbohos, very large baskets and exterior granaries are grouped in Tables 6.4, 6.5 and 6.6. The results for the metal and plastic drums are grouped in Tables 6.7, 6.8 and 6.9.

The results are quite variable and difficult to interpret. Part of this variability may be due to the beans which were obtained from different souces and were composed of complex varietal mixtures. The inherent variability of the containers themselves may also be a contributing factor. The subjectivity of certain quality analyses (e.g. discoloration), differences among technicians and the heterogeneous nature of some changes occurring within grain during storage (e.g. insect numbers, damage) may also account for some of this variability. Conclusions drawn at this time must be considered tentative. Additional experiments should be conducted to confirm these results and prior to making any firm recommendations.

Moisture contents (Tables 6.1, 6.4, 6.7) are shown as target values at the first sampling time. Moisture contents in the traditional containers (Tables 6.1 and 6.4) moved toward equilibrium with the surrounding air conditions since they did not provide vapor barriers. Containers filled with 11 % beans generally increased in moisture content while containers filled with 16.5 % beans decreased in moisture content. Containers filled with 13 % beans tended to fluctuate with the external conditions. The metal and plastic drums were impermeable to vapor movement and the bean moisture contents remained essentially constant.

The total number of insects (dead and live combined) per kg (Tables 6.1, 6.4, 6.7) was highly variable with relatively high numbers (>20) found in some but not all of the traditional types of containers. Within each container/moisture content treatment some containers had high levels (large basket at 11% moisture content in Table 6.1 or exterior granary at 11% moisture content in Table 6.4) while others of the same type did not. Many of these containers also showed significant increases between the second and fourth samplings. The metal and plastic drums (Table 6.7) which were intended to be 'air tight' also showed high total insect counts in many cases. Results were quite variable between sampling dates but pronounced trends of increased insect counts with time were not evident for these containers.

Most insects counted were dead, but live insects were found in selected containers. They occurred at relatively high levels in some of the large baskets (Table 6.1) and in one of the external granaries (Table 6.4). These results show that, despite insecticidal treatments, control failures (incomplete kill and/or reinfestation) can occur. The insect population must, therefore, be continually and closely monitored, even where insecticides are applied. Furthermore, more effective procedures for treating grain against insects should be developed.

Live insects were also found at low levels in one of the metal and two of the plastic drums (Table 6.7). Though insect control was not perfect or complete in all cases, at least partial control seems to have occurred even in those containers where some live insects were found. In fact, the control was probably sufficient given the length of the storage period and is considered promising enough to investigate further.

Percent hard-to-cook was generally high although there was considerable variability (Tables 6.1, 6.4 and 6.7). Instrumental hardness values were also high with considerable variability which confirmed the hard-to-cook values. The extremely high cookability values of many treatments in the October test (Sampling III) are suspicious and not consistent with analyses of later samplings or results from other studies.

Germination generally decreased with time (Tables 6.1, 6.4 and 6.7). Even well-dried beans, regardless of container, did not exceed a mean germination rate of 50% after one year, which is considered poor for seed purposes. Decreases in germination were most pronounced in the beans stored at the 16.5% moisture content experiments in the metal and plastic drums (Table 6.7). The germination at the final sampling was at or near zero. Maintaining the moisture content near the initial level for the entire storage period resulted in almost total loss of germination.

Insect damage (Tables 6.2, 6.5 and 6.8) was variable; however, the two instances with very high insect counts (container 1 in the large baskets and container 4 of the exterior granaries) showed corresponding high levels of insect damage.

Mold results (Tables 6.2, 6.5 and 6.8) were also highly variable. Interestingly the highest levels of mold were found in the experiments at the low (11%) moisture level. Examples include the medium baskets (Table 6.2), clay pots (Table 6.5), exterior granaries (Table 6.5), metal drums (Table 6.8) and plastic drums (Table 6.8). At this moisture level mold problems would not normally be expected. There is no obvious explanation for the occurrence of high mold levels at the low moisture contents.

There were no significant trends in rodent damaged, germinated, broken or torn pericarp beans (Tables 6.2, 6.5 and 6.8). Discolored beans (Table 6.2, 6.5 and 6.8) increased markedly with time (see discussion in Section 5.1.2.1.). No patterns emerged for small, wrinkled and dented damage categories as expected (Tables 6.3, 6.6 and 6.9).

Total storage damage (sum of damage caused by insects, molds, rodents and germination) followed the pattern established for insect and mold damaged beans (Tables 6.3, 6.6 and 6.9). Inedible and unplantable values (Tables 6.3, 6.6 and 6.9) were generally high but also quite variable. The highest levels correspond to containers with high insect or mold damage.

Table 6.1. Changes in quality (moisture content...germination) of Rwandan beans stored in small, medium and large baskets. (Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

	Container No.	Moisture Content (%)				Test Weight kg/m^3			Foreign Mat. (%)			Tot. insects per kg.			Tot. live ins. per kg.			Mean Hardness (Newton)				Hard-to-cook (%)				Germination (%)		
		I	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	I	II	III	IV	I	II	III	IV	II	III	IV
Small Basket	4	-	12.3	11.2	12.1	711	720	712	0.33	0.39	0.36	6	4	9	0.0	-	0.0	-	3.47	4.27	4.26	-	16	60	60	61	90	46
	5	-	12.6	11.4	12.2	712	711	717	0.40	0.43	0.57	3	9	8	0.0	-	0.0	-	3.16	4.11	3.91	-	20	51	50	59	87	28
	6	-	12.6	11.5	12.2	710	734	712	0.24	0.32	0.39	6	1	11	0.0	-	0.0	-	3.21	4.17	3.75	-	24	65	42	57	89	21
	Mean	11.0	12.5	11.3	12.2	711	722	714	0.32	0.38	0.44	5	5	9	0.0	-	0.0	2.98	3.28	4.18	3.97	15	20	59	51	59	88	31
	1	-	13.3	11.4	12.8	711	712	720	0.41	0.17	0.42	5	3	9	0.0	0.0	0.0	-	3.18	4.10	3.70	-	26	55	33	73	84	16
	2	-	13.6	11.6	12.7	700	715	726	0.41	0.44	0.65	25	39	79	0.0	0.0	0.0	-	3.20	4.20	3.26	-	21	57	27	83	74	20
	3	-	12.9	11.5	12.4	704	719	726	0.36	0.60	0.55	4	35	89	0.0	0.0	0.0	-	2.59	4.04	3.51	-	7	53	34	72	79	17
	Mean	13.0	13.3	11.5	12.6	705	715	724	0.39	0.40	0.54	11	26	59	0.0	0.0	0.0	2.98	2.99	4.11	3.49	15	18	55	31	76	79	18
Medium Basket	2	-	12.1	-	11.7	720	-	705	0.49	-	0.33	10	-	1	0.0	-	0.0	-	2.59	-	3.55	-	9	-	35	56	-	26
	4	-	12.0	-	11.7	706	-	717	0.44	-	0.32	3	-	5	0.0	-	0.0	-	2.84	-	3.52	-	17	-	32	45	-	14
	5	-	12.2	-	11.6	707	-	719	0.48	-	0.39	0	-	6	0.0	-	0.0	-	2.86	-	3.58	-	9	-	36	44	-	14
	Mean	11.0	12.1	-	11.7	711	-	714	0.47	-	0.35	4	-	4	0.0	-	0.0	2.98	2.77	-	3.55	15	12	-	34	48	-	18
	6	-	13.4	-	12.4	722	-	720	0.33	-	0.47	6	-	11	0.0	-	0.0	-	3.54	-	3.54	-	37	-	35	60	-	17
	7	-	13.1	-	12.1	720	-	715	0.21	-	0.16	1	-	4	0.0	-	0.0	-	3.14	-	3.54	-	19	-	34	50	-	10
	8	-	13.1	-	12.2	719	-	711	0.30	-	0.22	4	-	8	0.0	-	0.0	-	2.90	-	3.50	-	15	-	27	49	-	9
	Mean	13.0	13.2	-	12.2	720	-	715	0.28	-	0.28	4	-	8	0.0	-	0.0	2.98	3.19	-	3.53	15	24	-	32	53	-	12
	1	-	14.2	-	12.6	713	-	703	0.55	-	0.59	23	-	44	0.0	-	0.0	-	2.73	-	3.34	-	6	-	29	35	-	16
	3	-	14.3	-	12.8	716	-	720	0.43	-	0.48	14	-	24	0.0	-	0.0	-	2.83	-	3.53	-	12	-	30	35	-	19
	9	-	14.0	-	12.5	711	-	707	0.41	-	0.29	18	-	14	0.0	-	0.0	-	3.08	-	3.43	-	21	-	23	40	-	37
	Mean	16.5	14.1	-	12.6	713		710	0.46	-	0.45	18	-	27	0.0	-	0.0	3.22	2.88	-	3.43	23	13	-	27	36	-	24
Large Basket	1	-	11.9	-	11.5	726	-	711	0.36	-	0.37	19	-	676	0.0	-	53.6	-	2.95	-	4.02	-	16	-	46	68	-	30
	2	-	11.7	-	11.5	730	-	715	0.39	-	0.30	9	-	5	0.0	-	0.0	-	3.11	-	3.78	-	20	-	40	90	-	57
	3	-	11.6	-	11.5	724	-	740	0.58	-	1.45	14	-	22	0.0	-	0.0	-	3.24	-	4.11	-	28	-	52	91	-	51
	Mean	11.0	11.7	-	11.5	727	-	722	0.44	-	0.71	14	-	234	0.0	-	17.9	2.98	3.10	-	3.97	15	21	-	46	83	-	46
	4	-	13.2	-	12.6	720	-	718	0.15	-	0.38	6	-	5	0.0	-	0.0	-	3.62	-	3.87	-	32	-	41	60	-	24
	5	-	13.8	-	12.5	713	-	718	0.29	-	0.34	1	-	43	0.0	-	19.0	-	2.77	-	4.20	-	14	-	49	33	-	12
	6	-	13.7	-	12.3	711	-	731	0.36	-	0.36	5	-	7	0.0	-	0.0	-	2.91	-	3.77	-	15	-	45	-	-	34
	9	-	13.8	-	13.0	704	-	714	0.79	-	0.27	21	-	19	0.0	-	0.0	-	3.18	-	4.13	-	24	-	47	74	-	35
	Mean	13.0	13.6	-	12.6	712	-	720	0.40	-	0.34	9	-	23	0.0	-	4.7	2.98	3.12	-	4.00	15	21	-	46	56	-	26
	7	-	14.4	-	13.0	709	-	717	0.42	-	0.40	12	-	41	0.0	-	0.0	-	2.89	-	4.21	-	17	-	52	38	-	43
	8	-	14.3	-	13.5	705	-	710	0.54	-	0.59	5	-	63	0.0	-	0.0	-	2.58	-	3.68	-	14	-	33	39	-	14
	10	-	14.6	-	12.6	711	-	728	0.73	-	0.82	32	-	34	0.0	-	0.0	-	2.47	-	4.14	-	6	-	58	59	-	20
	Mean	16.5	14.5	-	13.1	709	-	718	0.56	-	0.60	16	-	46	0.0	-	0.0	3.22	2.65	-	4.01	23	12	-	48	45	-	25

Table 6.2. Changes in damage (insect...torn pericarp) of Rwandan beans stored in small, medium and large baskets.
(Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

Container	No.	Insect (%)			Mold (%)			Rodent (%)			Germinated (%)			Broken (%)			Discolored (%)			Torn Pericarp (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Small Basket	4	1.7	2.3	0.7	0.7	3.0	3.3	0.3	0.0	0.0	0.0	0.7	0.7	0.7	1.0	0.3	9.0	21.0	11.0	1.0	0.7	1.7
	5	0.3	0.7	0.7	0.3	1.7	1.7	0.0	0.7	0.0	0.3	0.0	0.0	2.3	0.7	1.7	9.3	28.0	9.3	1.0	0.7	2.0
	6	0.0	1.0	0.0	0.0	0.3	2.3	0.0	0.0	0.0	0.3	0.0	0.0	0.7	0.3	2.0	14.3	16.3	10.3	0.3	0.7	1.7
	Mean	0.7	1.3	0.5	0.3	1.7	2.4	0.1	0.2	0.0	0.2	0.2	0.2	1.2	0.7	1.3	10.9	21.8	10.2	0.8	0.7	1.8
	1	1.7	1.7	0.7	0.7	5.0	3.3	0.7	1.3	0.7	0.3	0.3	0.7	1.0	0.7	0.3	10.0	22.4	10.7	1.0	1.3	1.7
	2	2.0	1.7	2.3	0.0	2.7	4.7	0.3	0.0	0.7	0.0	0.3	0.0	1.7	0.0	0.7	4.7	25.3	12.3	1.0	1.0	1.0
	3	1.0	2.7	1.3	0.7	1.3	4.7	0.0	0.0	0.0	0.0	0.0	0.3	1.0	1.0	1.7	17.7	31.3	12.0	1.0	0.3	1.0
	Mean	1.6	2.0	1.4	0.5	3.0	4.2	0.3	0.4	0.5	0.1	0.2	0.3	1.2	0.6	0.9	10.8	26.3	11.7	1.0	0.9	1.2
Medium Basket	2	1.0	--	0.0	9.3	--	10.3	0.0	--	0.0	1.7	--	0.0	1.0	--	1.0	13.7	--	25.0	2.7	--	0.7
	4	0.0	--	0.0	0.0	--	6.3	0.0	--	0.0	0.0	--	0.3	1.3	--	0.0	7.0	--	25.0	1.0	--	2.0
	5	0.0	--	2.0	10.0	--	1.3	0.0	--	0.3	0.0	--	0.3	3.3	--	0.3	10.3	--	40.3	2.0	--	0.3
	Mean	0.3	--	0.7	6.4	--	6.0	0.0	--	0.1	0.6	--	0.2	1.9	--	0.4	10.3	--	30.1	1.9	--	1.0
	6	0.0	--	0.7	1.0	--	1.0	2.3	--	0.0	0.0	--	0.3	2.3	--	0.0	10.0	--	25.3	1.0	--	0.3
	7	1.7	--	1.0	0.7	--	0.7	0.7	--	0.0	0.0	--	0.0	1.0	--	1.3	13.7	--	22.0	2.3	--	0.0
	8	0.0	--	0.0	0.7	--	0.0	0.3	--	0.3	0.0	--	0.7	1.7	--	0.3	15.0	--	23.3	0.0	--	0.7
	Mean	0.6	--	0.6	0.8	--	0.6	1.1	--	0.1	0.0	--	0.3	1.7	--	0.5	12.9	--	23.5	1.1	--	0.3
	1	1.7	--	2.3	7.0	--	1.3	0.0	--	0.3	1.0	--	0.3	1.3	--	0.3	10.0	--	32.3	1.0	--	1.0
	3	1.3	--	0.0	1.0	--	7.7	0.0	--	0.3	0.0	--	0.3	1.0	--	1.3	12.3	--	24.7	0.7	--	1.7
	9	0.7	--	0.0	1.7	--	0.7	1.0	--	0.0	0.0	--	0.0	1.3	--	0.0	16.0	--	31.7	0.3	--	1.3
	Mean	1.2	--	0.8	3.2	--	3.2	0.3	--	0.2	0.3	--	0.2	1.2	--	0.5	12.8	--	29.6	0.7	--	1.3
Large Basket	1	0.7	--	28.7	1.0	--	0.3	0.3	--	0.0	0.0	--	0.0	0.3	--	0.7	12.3	--	14.3	0.0	--	0.0
	2	1.3	--	1.0	1.0	--	2.0	0.7	--	0.0	0.0	--	0.0	1.0	--	1.0	7.3	--	23.3	1.7	--	0.3
	3	1.3	--	0.7	0.0	--	1.3	0.0	--	0.3	0.0	--	0.0	0.7	--	0.7	11.3	--	15.0	1.0	--	0.7
	Mean	1.1	--	10.1	0.7	--	1.2	0.3	--	0.1	0.0	--	0.0	0.7	--	0.8	10.3	--	17.5	0.9	--	0.3
	4	1.0	--	0.3	0.3	--	1.0	0.0	--	0.7	0.3	--	0.0	0.3	--	0.0	11.0	--	24.7	0.0	--	0.7
	5	0.0	--	1.7	0.7	--	0.7	1.3	--	1.0	0.7	--	0.3	0.7	--	0.3	6.7	--	32.0	1.7	--	0.3
	6	0.7	--	0.3	1.0	--	0.3	0.3	--	0.0	0.0	--	0.0	1.3	--	0.3	8.7	--	27.3	1.7	--	0.7
	9	1.0	--	1.0	1.0	--	0.3	0.7	--	0.0	0.0	--	0.3	1.0	--	0.0	6.3	--	24.7	0.3	--	0.0
	Mean	0.7	--	0.8	0.8	--	0.6	0.6	--	0.4	0.3	--	0.2	0.8	--	0.2	8.2	--	27.2	0.9	--	0.4
	7	4.0	--	1.7	1.3	--	1.3	0.0	--	0.0	0.0	--	0.7	0.3	--	0.0	11.3	--	18.0	0.0	--	0.3
	8	1.3	--	1.0	1.0	--	0.7	0.0	--	0.0	0.7	--	0.0	1.3	--	0.0	8.7	--	21.7	0.7	--	0.3
	10	1.3	--	2.0	1.7	--	0.7	0.0	--	1.0	0.7	--	0.3	2.0	--	0.0	10.3	--	21.0	1.7	--	0.7
	Mean	2.2	--	1.6	1.3	--	0.9	0.0	--	0.3	0.5	--	0.3	1.2	--	0.0	10.1	--	20.2	0.8	--	0.4

Table 6.3. Changes in damage (small beans...unplantable) of Rwandan beans stored in small, medium and large baskets. (Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

	Container No.	Small (%)			Wrinkled (%)			Dented (%)			Total Storage Damage (%)			Inedible (%)			Unplantable (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Small Basket	4	7.7	13.0	11.0	5.3	2.7	2.0	6.7	2.0	10.0	2.7	6.0	4.7	13.0	17.3	8.0	18.7	27.3	20.7
	5	0.0	13.0	7.0	5.0	5.0	8.0	5.7	1.7	10.3	0.9	3.1	2.4	9.3	13.0	8.7	14.0	24.0	16.7
	6	5.0	12.3	8.3	3.3	3.7	2.7	5.3	3.7	11.3	0.3	1.3	2.3	12.7	13.0	10.0	16.7	24.3	16.3
	Mean	4.2	12.8	8.8	4.5	3.8	4.2	5.9	2.5	10.5	1.3	3.5	3.1	11.7	14.4	8.9	16.5	25.2	17.9
	1	8.0	14.7	7.3	6.7	12.7	3.3	1.3	9.3	10.0	3.4	8.3	5.4	10.0	18.3	6.0	15.7	31.7	15.7
	2	10.0	13.3	4.3	8.7	10.7	4.0	3.3	5.0	5.7	2.3	4.7	7.7	13.7	19.3	5.3	19.0	30.7	16.3
	3	9.7	17.3	9.0	4.3	2.7	5.3	7.0	3.0	7.7	1.7	4.0	6.3	17.3	19.3	7.3	24.3	32.7	19.0
	Mean	9.2	15.1	6.9	6.6	8.7	4.2	3.9	5.8	7.8	2.5	5.7	6.5	13.7	19.0	6.2	19.7	31.7	17.0
Medium Basket	2	7.0	-	12.7	4.7	-	9.0	9.3	-	4.7	12.0	-	10.3	21.7	-	11.7	29.7	-	20.7
	4	5.0	-	15.3	8.0	-	8.3	5.3	-	5.0	0.0	-	6.6	9.7	-	15.7	13.7	-	26.7
	5	11.3	-	8.0	4.3	-	4.3	9.7	-	2.7	10.0	-	3.9	25.3	-	10.7	35.0	-	17.0
	Mean	7.8	-	12.0	5.7	-	7.2	8.1	-	4.1	7.3	-	6.9	18.9	-	12.7	26.1	-	21.5
	6	9.7	-	11.3	1.3	-	2.7	4.3	-	4.7	3.3	-	2.0	11.0	-	11.0	17.0	-	18.7
	7	10.3	-	9.7	3.0	-	3.7	3.7	-	4.3	3.1	-	1.7	14.0	-	10.7	19.7	-	21.0
	8	11.3	-	7.0	5.7	-	3.7	8.7	-	3.7	1.0	-	1.0	16.0	-	8.0	22.0	-	16.3
	Mean	10.4	-	9.3	3.3	-	3.4	5.6	-	4.2	2.5	-	1.6	13.7	-	9.9	19.6	-	18.7
	1	8.7	-	11.3	3.7	-	1.7	10.7	-	4.0	9.7	-	4.2	20.0	-	12.7	29.0	-	22.0
	3	2.3	-	9.3	5.7	-	8.0	6.0	-	5.3	2.3	-	8.3	13.3	-	10.3	18.0	-	21.0
	9	9.0	-	13.0	2.7	-	6.0	5.3	-	2.0	3.4	-	0.7	12.0	-	11.7	16.0	-	21.3
	Mean	6.7	-	11.2	4.0	-	5.2	7.3	-	3.8	5.1	-	4.4	15.1	-	11.6	21.0	-	21.4
Large Basket	1	6.7	-	12.0	5.3	-	1.3	5.3	-	2.7	2.0	-	29.0	11.3	-	30.3	15.7	-	36.3
	2	2.3	-	11.0	8.3	-	4.3	4.0	-	3.3	3.0	-	3.0	11.0	-	8.3	15.3	-	14.7
	3	6.7	-	9.0	8.7	-	4.3	4.3	-	3.7	1.3	-	2.3	15.3	-	7.3	10.7	-	14.7
	Mean	5.2	-	10.7	7.4	-	3.3	4.5	-	3.2	2.1	-	11.4	12.5	-	15.3	13.9	-	21.9
	4	6.0	-	11.0	1.7	-	3.0	7.7	-	4.7	1.6	-	2.0	10.0	-	9.7	13.7	-	17.3
	5	4.0	-	10.7	3.0	-	4.0	7.7	-	3.3	2.7	-	3.7	10.0	-	11.7	14.0	-	20.7
	6	2.7	-	5.7	4.3	-	4.7	4.3	-	3.3	2.0	-	0.6	11.0	-	11.3	13.7	-	18.0
	9	8.7	-	7.7	3.0	-	3.7	3.7	-	2.0	2.7	-	1.6	11.0	-	9.3	14.3	-	16.3
	Mean	5.4	-	8.8	3.0	-	3.9	5.9	-	3.3	2.3	-	2.0	10.5	-	10.5	13.9	-	18.1
	7	1.7	-	8.0	5.3	-	5.0	4.3	-	5.7	5.3	-	3.7	12.7	-	8.0	16.0	-	15.3
	8	6.7	-	14.0	5.0	-	4.7	3.3	-	2.3	3.0	-	1.7	11.7	-	10.0	16.3	-	15.0
	10	8.3	-	9.7	4.0	-	5.0	2.0	-	2.0	3.7	-	4.0	13.3	-	10.7	17.0	-	17.3
	Mean	5.6	-	10.6	4.8	-	4.9	3.2	-	3.3	4.0	-	3.1	12.6	-	9.6	16.4	-	15.9

Table 6.4. Changes in quality (moisture content...germination) of Rwandan beans stored in clay pots, imbohos, very large baskets and exterior granaries. (Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - Februay 3, 1987)

	Container No.	Moisture Content (%)				Test Weight kg/m^3			Foreign Mat. (%)			Tot. insects per kg.			Tot. live ins. per kg.			Mean Hardness (Newton)				Hard-to-cook (%)				Germination (%)		
		I	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	I	II	III	IV	I	II	III	IV	II	III	IV
Clay Pot	1	-	12.0	11.3	11.6	713	713	726	0.24	0.24	0.51	3	5	6	0.0	0.0	0.0	-	3.39	4.11	3.63	-	35	59	31	58	78	32
	2	-	12.0	11.2	11.6	711	729	716	0.45	0.40	0.51	6	2	0	0.0	0.0	0.0	-	2.83	4.50	3.54	-	10	68	25	80	65	30
	3	-	11.6	11.1	11.7	714	711	720	0.34	0.34	0.48	4	4	4	0.0	0.0	0.0	-	3.09	4.58	3.79	-	32	79	35	26	60	34
	Mean	11	11.8	11.2	11.6	712	717	721	0.34	0.33	0.50	4	4	3	0.0	0.0	0.0	2.98	3.10	4.40	3.65	15	26	69	30	54	67	32
	4	-	12.9	12.2	12.5	713	727	730	0.36	0.60	0.56	10	15	11	0.0	0.0	0.0	-	3.60	4.56	3.47	-	41	72	34	50	68	10
	5	-	12.4	11.9	12.3	711	719	717	0.47	0.47	0.28	9	8	8	0.0	0.0	0.0	-	3.45	4.32	3.40	-	29	59	25	56	83	39
	6	-	12.2	12.0	12.0	718	710	728	0.24	0.30	1.17	5	18	16	0.0	0.0	0.0	-	3.02	4.15	3.48	-	27	59	27	54	66	27
	Mean	13	12.5	12.0	12.3	714	719	725	0.36	0.46	0.67	8	13	12	0.0	0.0	0.0	2.98	3.36	4.35	3.45	15	32	63	29	53	72	25
Imboho	1	-	12.3	11.5	11.8	727	743	746	0.15	0.45	0.28	0	1	0	0.0	0.0	0.0	-	2.60	3.67	3.44	14	7	35	25	64	48	41
	2	-	12.6	11.4	10.6	729	726	745	0.19	0.30	0.54	0	1	1	0.0	0.0	0.0	-	2.75	3.43	3.16	14	9	26	22	86	46	53
	3	-	12.7	11.3	11.9	734	729	713	0.43	0.27	0.53	0	2	1	0.0	0.0	0.0	-	2.88	3.84	3.36	15	12	38	24	78	84	54
	Mean	13	12.5	11.4	11.4	730	733	735	0.26	0.34	0.45	0	2	1	0.0	0.0	0.0	2.98	2.74	3.65	3.32	14	9	33	24	76	60	50
Very Large Basket	7	-	14.2	-	13.6	712	-	714	0.52	-	0.75	18	-	22	0.0	-	0.0	-	3.08	-	3.43	-	16	-	34	63	-	30
	3	-	14.9	-	13.5	710	-	702	0.68	-	0.37	19	-	16	0.0	-	0.0	-	3.17	-	4.28	-	33	-	57	60	-	27
	Mean	16.5	14.5	-	13.6	711	-	708	0.60	-	0.56	19	-	19	0.0	-	0.0	3.22	3.12	-	3.86	23	25	-	46	61	-	28
Exterior Granary	2	-	12.5	11.5	12.0	714	714	709	0.34	0.78	0.27	18	11	4	0.0	0.0	0.0	-	2.71	3.77	3.39	16	10	49	31	44	-	41
	4	-	12.2	12.0	12.4	715	721	657	0.34	1.02	0.44	6	18	269	0.0	0.0	113.3	-	3.04	3.87	3.70		19	50	33	55	-	32
	Mean	11	12.3	11.7	12.2	715	718	683	0.34	0.90	0.36	12	15	137	0.0	0.0	56.7	2.98	2.87	3.82	3.55	16	15	50	32	49	-	36
	3	13	12.9	12.7	13.6	713	704	713	0.31	0.97	0.42	5	22	3	0.0	0.0	0.0	-	2.66	3.29	4.11	-	9	28	51	53	-	34

Table 6.5. Changes in damage (insect...torn pericarp) of Rwandan beans stored in clay pots, imbohos, very large baskets and exterior granaries. (Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

Container	No.	Insect (%)			Mold (%)			Rodent (%)			Germinated (%)			Broken (%)			Discolored (%)			Torn Pericarp (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Clay Pot	1	0.0	0.0	1.0	1.3	12.7	7.3	0.3	1.3	0.7	0.0	0.0	0.0	1.0	0.0	0.0	10.3	23.3	29.7	1.0	1.7	0.3
	2	4.0	0.3	0.0	0.3	19.3	3.7	0.0	0.6	0.3	0.3	0.3	0.3	0.0	0.0	0.0	9.0	19.3	26.7	0.7	0.0	0.7
	3	0.0	1.0	0.0	1.7	9.7	5.0	0.7	0.0	0.7	0.0	0.0	1.0	1.7	1.0	0.0	7.7	21.0	30.3	0.7	0.7	1.3
	Mean	1.3	0.4	0.3	1.1	13.9	5.3	0.3	0.6	0.6	0.1	0.1	0.4	0.9	0.3	0.0	9.0	21.2	28.9	0.8	0.8	0.8
	4	1.0	1.7	0.0	1.0	2.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.7	0.7	1.0	6.7	22.3	29.7	0.0	0.7	1.3
	5	0.3	0.3	1.0	0.7	2.7	0.7	0.3	0.0	0.0	0.0	0.3	0.0	2.0	0.3	1.3	15.7	32.3	19.0	1.0	0.3	2.7
	6	1.0	1.3	2.0	2.0	3.0	0.0	0.0	1.0	0.7	0.0	0.0	0.3	0.7	0.0	1.7	14.7	19.3	26.0	1.7	1.0	0.3
	Mean	0.8	1.1	1.0	1.2	2.6	0.2	0.1	0.4	0.2	0.0	0.2	0.1	1.1	0.3	1.3	12.4	24.6	24.9	0.9	0.7	1.4
Imboho	1	0.0	0.0	0.0	6.7	3.3	4.7	0.3	0.0	0.0	1.0	0.0	0.3	0.7	0.3	0.7	9.0	25.7	6.3	0.7	1.3	1.3
	2	0.0	0.0	0.3	0.7	4.0	4.0	1.0	0.6	0.3	0.3	0.0	0.0	1.0	1.0	0.7	8.0	21.7	8.3	1.0	1.0	1.3
	3	0.0	0.3	0.0	0.0	1.6	1.3	0.7	0.0	0.7	0.3	0.0	0.3	1.0	0.0	0.0	9.0	22.3	9.7	0.7	0.0	0.7
	Mean	0.0	0.1	0.1	2.5	3.0	3.3	0.7	0.2	0.3	0.5	0.0	0.2	0.9	0.4	0.5	8.7	23.2	8.1	0.8	0.8	1.1
Very large Basket	1	0.0	--	0.3	1.7	--	0.0	0.0	--	0.7	0.3	--	0.3	1.0	--	1.7	8.0	--	32.3	1.3	--	1.7
	2	0.7	--	1.0	1.0	--	0.0	0.3	--	0.3	0.0	--	0.0	0.7	--	0.0	15.0	--	25.0	0.3	--	1.0
	Mean	0.4	--	0.7	1.4	--	0.0	0.2	--	0.5	0.2	--	0.2	0.9	--	0.9	11.5	--	28.7	0.8	--	1.4
Exterior Granary	2	1.0	1.3	1.7	0.7	3.3	8.3	0.3	0.3	0.0	0.0	0.0	0.3	0.7	0.6	0.7	9.3	15.6	10.3	0.7	0.0	1.0
	4	2.0	0.6	41.7	1.0	3.6	10.7	0.3	0.3	0.0	0.3	0.3	0.3	0.7	1.6	0.7	6.3	16.6	5.3	0.0	0.3	0.3
	Mean	1.5	1.0	21.7	0.9	3.5	9.5	0.3	0.3	0.0	0.2	0.2	0.3	0.7	1.1	0.7	7.8	16.1	7.8	0.4	0.2	0.7
	3	1.3	0.6	0.0	0.7	1.0	3.7	0.3	0.0	0.3	0.0	0.0	1.0	0.7	0.0	0.3	11.3	23.6	10.0	1.3	0.3	0.3

Table 6.6. Changes in damage (small beans...unplantable) of Rwandan beans stored in clay pots, imbohos, very large baskets and exterior granaries. (Samplings: I (initial) - Feb.-March 1986; II - June 27, 1986; III - October 30, 1986; IV - Februay 3, 1987)

		Small (%)			Wrinkled (%)			Dented (%)			Total Storage Damage (%)			Inedible (%)			Unplantable (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Clay Pot	1	4.7	9.0	15.3	5.0	9.3	4.3	6.7	11.3	7.0	1.6	14.0	9.0	12.0	18.3	16.7	15.3	32.3	27.0
	2	2.3	12.6	13.7	4.0	5.7	0.7	3.0	9.3	4.0	4.6	20.5	4.3	9.7	23.7	10.3	14.0	35.3	21.7
	3	6.3	20.3	11.7	4.7	5.7	2.3	4.7	5.7	5.7	2.4	10.7	6.7	12.7	17.0	12.3	16.0	30.0	23.7
	Mean	4.4	14.0	13.6	4.6	6.9	2.4	4.8	8.8	5.6	2.9	15.1	6.7	11.5	19.7	13.1	15.1	32.5	24.1
	4	3.3	17.0	7.0	6.3	5.3	4.7	4.7	3.3	5.0	2.0	4.3	0.0	10.3	17.3	7.7	16.0	30.7	14.3
	5	4.0	13.7	9.0	3.0	3.3	4.3	7.0	5.3	4.0	1.3	3.3	1.7	12.0	15.0	9.3	21.0	27.3	18.0
	6	5.3	13.0	8.7	4.0	4.3	1.7	9.7	4.7	4.3	3.0	5.3	3.0	9.7	11.7	9.0	20.0	23.3	18.3
	Mean	4.2	14.6	8.2	4.4	4.3	3.6	7.1	4.4	4.4	2.1	4.3	1.6	10.7	14.7	8.7	19.0	27.1	16.9
Imboho	1	5.7	12.0	5.3	3.7	6.0	10.0	10.3	5.0	11.7	8.0	3.3	5.0	11.7	13.7	8.0	20.3	25.3	16.3
	2	7.0	12.3	6.3	8.7	8.0	4.3	13.0	6.6	15.7	2.0	4.6	4.6	13.0	14.6	8.7	19.7	24.3	16.3
	3	10.7	10.6	7.0	8.3	9.0	6.0	6.3	4.0	13.0	1.0	1.9	2.3	14.7	11.0	5.0	20.7	23.7	13.3
	Mean	7.8	11.6	6.2	6.9	7.7	6.8	9.9	5.2	13.5	3.7	3.3	4.0	13.1	13.1	7.2	20.2	24.4	15.3
Very Large Basket	1	12.7	-	10.0	5.3	-	2.3	3.7	-	2.7	2.0	-	1.3	13.0	-	9.3	16.0	-	16.3
	2	8.3	-	12.7	5.0	-	4.0	3.3	-	4.0	2.0	-	1.3	14.3	-	8.3	18.7	-	18.3
	Mean	10.5	-	11.4	5.2	-	3.2	3.5	-	3.4	2.0	-	1.3	13.7	-	8.8	17.4	-	17.3
Exterior Granary	2	4.3	17.6	4.0	4.3	5.3	5.7	6.7	4.0	10.0	2.0	4.9	10.3	12.0	15.6	11.7	15.7	23.6	22.3
	4	5.0	16.0	6.3	11.0	5.6	2.3	7.0	4.3	10.0	3.6	4.8	52.7	14.3	15.0	54.0	22.7	25.6	62.0
	Mean	4.7	16.8	5.2	7.7	5.5	4.0	6.9	4.2	10.0	2.8	4.9	31.5	13.2	15.3	32.9	19.2	24.6	42.2
	3	2.3	21.0	8.3	4.7	4.3	5.3	3.3	5.0	7.3	2.3	1.6	5.0	11.0	14.3	8.3	14.0	27.6	16.7

Table 6.7. Changes in quality (moisture content...germination) of Rwandan beans stored in metal and plastic drums.
(Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

	Container No.	Moisture Content (%)				Test Weight kg/m³			Foreign Mat. (%)			Tot. insects per kg.			Tot. live ins. per kg.			Mean Hardness (Newton)				Hard-to-cook (%)				Germination (%)		
		I	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	I	II	III	IV	I	II	III	IV	II	III	IV
Metal Drum	1	-	11.1	11.1	11.3	721	741	728	0.15	0.45	0.24	1	70	17	0.0	0.0	0.0	-	3.15	3.37	3.60	-	24	24	31	52	49	32
	2	-	11.2	11.1	11.0	727	735	741	0.47	0.64	0.16	19	83	11	0.0	0.0	0.0	-	3.30	3.21	3.33	-	32	23	24	65	58	21
	3	-	11.3	11.3	11.4	725	734	742	0.53	0.72	0.38	20	32	47	0.0	0.0	2.4	-	3.60	3.19	3.84	-	35	27	39	65	36	53
	Mean	11	11.2	11.2	11.3	725	737	737	0.38	0.60	0.26	13	62	25	0.0	0.0	0.8	-	3.35	3.25	3.59	-	30	25	31	61	48	35
	4	-	13.1	13.1	12.9	729	741	733	0.46	0.50	0.28	9	66	4	0.0	0.0	0.0	-	3.48	3.47	3.53	-	33	28	34	58	30	20
	5	-	13.3	13.0	13.1	727	744	730	0.36	0.54	0.19	1	51	2	0.0	0.0	0.0	-	3.54	3.19	3.81	-	36	23	48	50	42	34
	6	-	13.1	13.0	12.9	728	731	735	0.39	0.52	0.39	11	11	28	0.0	0.0	0.0	-	3.26	3.55	3.69	-	26	35	38	38	58	32
	Mean	13	13.2	13.1	12.9	728	739	733	0.40	0.52	0.29	7	43	12	0.0	0.0	0.0	-	3.43	3.40	3.68	-	32	29	40	48	43	29
	7	-	17.3	17.2	15.9	720	724	731	0.32	0.28	0.16	1	0	0	0.0	0.0	0.0	-	3.65	4.16	4.29	-	33	58	56	44	0	0
	8	-	16.2	16.8	16.7	722	727	708	0.45	0.37	0.14	9	9	3	0.0	0.0	0.0	-	3.31	3.91	4.21	-	31	42	60	18	0	0
	9	-	16.8	16.6	16.0	718	730	724	0.20	0.32	0.28	0	16	3	0.0	0.0	0.0	-	3.07	4.04	4.11	-	20	49	58	25	1	0
	Mean	16.5	16.8	16.9	16.2	720	727	721	0.32	0.32	0.19	3	8	2	0.0	0.0	0.0	-	3.34	4.04	4.20	-	28	50	58	29	0	0
Plastic Drum	1	11	11.2	11.1	11.3	714	722	718	0.39	0.32	0.46	9	18	29	0.0	0.0	1.3	-	2.40	3.64	3.41	-	5	40	23	67	70	32
	8	-	12.9	13.2	12.6	727	727	737	0.77	1.05	0.42	39	65	83	0.0	1.2	0.0	-	3.29	4.33	4.75	-	28	69	63	56	28	22
	9	-	12.8	13.0	13.5	732	750	729	0.35	0.40	0.39	35	21	52	0.0	0.0	0.0	-	2.72	4.59	3.77	-	15	82	44	51	45	4
	10	-	12.8	13.2	13.1	731	736	749	0.51	0.33	0.38	43	72	58	0.0	0.0	0.0	-	3.37	4.34	4.35	-	33	71	64	56	68	27
	Mean	13	12.8	13.1	13.1	730	738	738	0.54	0.59	0.40	39	52	64	0.0	0.4	0.0	-	3.13	4.42	4.29	-	25	74	57	54	47	17
	2	-	12.4	16.6	16.0	720	730	720	0.54	0.68	0.56	6	46	37	0.0	0.0	0.0	-	2.75	4.16	3.58	-	11	56	27	60	10	6
	3	-	17.1	16.3	15.6	714	717	724	0.61	0.46	0.60	6	8	9	0.0	0.0	0.0	-	2.91	3.61	3.74	-	14	39	41	47	10	1
	4	-	16.2	-	16.4	723	735	720	0.72	0.51	0.61	0	17	21	0.0	0.0	0.0	-	3.04	3.79	3.55	-	21	42	31	66	6	12
	5	-	16.9	17.3	16.5	717	711	717	0.41	0.20	0.19	1	5	1	0.0	0.0	0.0	-	3.57	4.68	4.16	-	29	86	49	22	1	0
	6	-	15.0	16.2	16.3	730	726	716	0.36	0.45	0.25	0	0	1	0.0	0.0	0.0	-	3.36	4.32	4.25	-	22	63	57	38	4	3
	7	-	17.3	-	16.6	722	732	727	0.29	0.48	1.26	0	2	2	0.0	0.0	0.0	-	3.28	4.63	4.39	-	15	85	68	20	0	0
	Mean	16.5	15.8	16.6	16.2	721	725	721	0.49	0.46	0.58	2	13	12	0.0	0.0	0.0	-	3.15	4.20	3.95	-	19	62	46	42	5	4

Table 6.8. Changes in damage (insect...torn pericarp) of Rwandan beans stored in metal and plastic drums. (Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

	Container No.	Insect (%)			Mold (%)			Rodent (%)			Germinated (%)			Broken (%)			Discolored (%)			Torn Pericarp (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Metal Drum	1	0.0	0.7	6.0	1.3	9.7	18.3	0.7	0.7	1.3	0.7	0.3	1.3	0.7	0.7	1.3	11.7	24.7	24.7	2.0	0.7	2.3
	2	1.7	4.7	1.3	1.7	5.7	4.3	0.7	0.0	0.3	0.0	0.3	0.3	0.7	0.3	0.0	13.0	19.0	24.7	0.0	0.0	0.3
	3	1.3	2.3	6.7	6.3	11.3	7.0	0.3	0.0	0.7	0.0	0.0	0.7	1.7	0.7	1.0	13.3	21.3	23.7	0.7	0.0	0.7
	Mean	1.0	2.6	4.7	3.1	8.9	9.9	0.6	0.2	0.8	0.2	0.2	0.8	1.0	0.6	0.8	12.7	21.7	24.4	0.9	0.2	1.1
	4	4.3	1.7	1.0	0.7	5.0	4.3	0.0	0.7	0.7	0.3	0.3	0.0	0.3	0.7	0.3	8.0	15.7	14.0	1.7	2.0	0.7
	5	1.0	4.0	2.0	0.7	6.0	1.7	0.3	0.7	0.7	0.3	0.0	0.0	0.3	1.0	0.7	9.0	14.0	25.7	0.3	4.3	1.0
	6	1.3	1.0	3.0	1.3	5.3	3.3	0.7	2.6	0.3	0.0	0.0	0.0	1.0	1.0	0.3	7.0	13.3	22.3	0.7	1.3	0.7
	Mean	2.2	2.2	2.0	0.9	5.4	3.1	0.3	1.3	0.6	0.2	0.1	0.0	0.5	0.9	0.4	8.0	14.3	20.7	0.9	2.5	0.8
	7	0.0	0.0	0.0	1.7	2.0	0.0	1.3	0.3	0.7	0.0	0.0	0.0	0.7	0.3	0.3	14.7	15.7	22.7	0.3	1.0	0.7
	8	2.3	0.6	0.0	0.3	2.6	1.3	0.3	0.0	0.7	0.0	0.0	0.0	1.3	0.3	0.7	10.3	14.0	27.0	1.0	0.0	1.0
	9	1.0	1.0	0.0	1.0	2.6	1.0	0.7	0.7	0.7	0.0	0.0	0.3	0.3	0.7	0.7	8.7	13.3	25.3	0.7	1.0	1.0
	Mean	1.1	0.5	0.0	1.0	2.4	0.8	0.8	0.3	0.7	0.0	0.0	0.1	0.8	0.4	0.6	11.2	14.3	25.0	0.7	0.7	0.9
Plastic Drum	1	1.0	0.0	3.3	1.0	7.3	10.0	0.0	0.0	0.3	0.0	0.0	0.3	0.7	0.3	1.0	7.0	19.0	8.3	0.7	0.6	0.7
	8	3.0	3.3	2.7	1.0	2.3	1.7	0.0	0.0	0.7	0.0	0.6	0.7	4.0	2.3	0.0	6.0	21.3	0.7	1.7	1.0	0.7
	9	6.7	2.0	4.7	1.0	1.3	1.7	0.3	0.3	0.3	0.7	0.3	0.3	1.0	1.3	2.7	6.7	16.3	7.7	1.0	0.7	0.7
	10	10.0	2.7	6.3	1.3	1.3	2.3	1.0	0.0	0.3	0.0	0.0	0.0	0.7	0.3	0.7	6.3	14.3	6.3	1.7	1.3	0.7
	Mean	6.6	2.7	4.6	1.1	1.6	1.9	0.4	0.1	0.4	0.2	0.3	0.3	1.9	1.3	1.1	6.3	17.3	4.9	1.5	1.0	0.7
	2	0.0	1.3	0.3	1.3	7.3	1.0	1.0	0.3	0.3	0.3	0.0	0.3	0.3	0.0	0.7	11.7	30.0	14.0	0.7	0.0	0.7
	3	0.7	0.6	0.7	0.7	8.0	3.0	0.7	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.7	15.7	27.0	13.7	0.0	0.6	1.7
	4	1.0	0.0	1.0	0.7	6.3	3.0	0.3	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.3	11.0	29.0	9.7	1.3	0.0	0.7
	5	0.0	0.0	0.7	1.7	1.3	1.0	0.7	0.0	0.0	0.0	0.3	0.3	0.7	0.0	0.0	15.3	14.0	11.7	2.3	0.0	0.7
	6	0.0	0.0	0.7	0.0	1.0	1.3	0.0	0.0	0.0	0.7	0.0	0.3	0.3	0.0	0.7	6.7	13.6	10.3	1.0	1.0	1.0
	7	0.0	0.0	1.0	2.0	2.3	2.0	1.3	0.6	1.3	0.3	0.0	0.0	1.7	0.0	0.7	16.3	19.3	11.3	1.7	0.0	0.7
	Mean	0.3	0.3	0.7	1.1	4.4	1.9	0.7	0.3	0.3	0.2	0.1	0.2	0.8	0.2	0.5	12.8	22.2	11.8	1.2	0.3	0.9

Table 6.9. Changes in damage (small beans...unplantable) for metal and plastic drums.
(Samplings: I (initial) - February-March 1986; II - June 27, 1986; III - October 30, 1986; IV - February 3, 1987)

		Small (%)			Wrinkled (%)			Dented (%)			Total Storage Damage (%)			Inedible (%)			Unplantable (%)		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
Metal	1	4.0	14.7	6.0	5.7	5.0	11.0	4.7	3.0	4.3	2.7	11.4	26.9	14.0	23.3	23.0	16.3	35.7	31.7
Drum	2	5.3	18.0	5.3	5.3	4.7	10.3	5.7	12.0	6.0	4.1	10.7	6.2	15.0	18.0	15.0	19.0	34.3	24.3
	3	7.7	18.0	6.0	9.0	9.3	5.7	3.0	4.0	5.7	7.9	13.6	15.1	14.3	23.0	21.0	18.0	35.0	26.3
	Mean	5.7	16.9	5.8	6.7	6.3	9.0	4.5	6.3	5.3	4.9	11.9	16.1	14.4	21.4	19.7	17.8	35.0	27.4
	4	12.3	10.0	9.0	3.3	3.3	5.3	2.3	10.7	10.7	5.3	7.7	6.0	13.0	15.3	11.3	18.3	28.3	18.7
	5	7.0	7.3	7.3	5.3	4.0	4.3	3.0	16.3	9.0	2.3	10.7	4.4	10.0	21.0	14.3	14.3	39.3	24.7
	6	6.0	13.0	10.3	5.0	3.3	4.3	4.7	13.6	6.0	3.3	8.9	6.6	10.3	13.0	14.3	15.3	26.7	23.0
	Mean	8.4	10.1	8.9	4.5	3.5	4.6	3.3	13.5	8.6	3.6	9.1	5.7	11.1	16.4	13.3	16.0	31.4	22.1
	7	5.7	6.6	9.7	4.3	3.0	5.3	3.3	3.0	6.7	3.0	2.3	0.7	12.0	12.7	11.3	16.0	22.3	17.3
	8	7.0	11.6	6.7	4.7	3.6	3.3	7.0	3.3	5.3	2.9	3.2	2.0	12.3	11.3	10.3	17.0	21.0	16.3
	9	7.0	14.0	6.3	4.7	4.0	4.0	6.7	3.3	7.0	2.7	4.3	2.0	12.0	13.7	10.7	16.3	24.7	20.3
	Mean	6.6	10.7	7.6	4.6	3.5	4.2	5.7	3.2	6.3	2.9	3.3	1.6	12.1	12.6	10.8	16.4	22.7	18.0
Plastic Drum	1	7.0	10.3	6.7	4.0	9.0	7.7	5.3	3.6	9.3	2.0	7.3	13.9	11.3	16.6	15.3	14.3	28.6	23.7
	8	5.3	10.3	4.7	5.3	2.6	5.7	3.3	3.6	10.3	4.0	6.2	5.8	11.3	12.6	6.3	15.7	25.0	13.3
	9	6.7	11.3	10.0	7.3	3.0	6.3	8.0	3.3	9.0	8.7	3.9	7.0	13.7	15.3	9.7	19.7	26.3	20.0
	10	4.3	10.7	7.3	5.3	6.3	3.7	8.3	3.3	18.9	12.3	4.0	8.9	14.3	14.3	13.3	20.0	25.0	16.3
	Mean	5.4	10.8	7.3	6.0	4.0	5.2	6.5	3.4	9.7	8.3	4.7	7.2	13.1	14.1	9.8	18.5	25.4	16.5
	2	6.7	9.3	9.7	6.0	10.0	3.7	5.7	4.3	9.7	2.6	8.9	1.9	12.0	18.6	5.0	19.3	30.0	13.3
	3	11.7	9.0	2.3	8.0	1.6	7.3	5.0	4.3	5.0	2.1	8.6	3.7	16.0	15.3	5.3	22.3	26.6	12.7
	4	7.3	14.0	5.3	7.0	7.0	5.3	2.7	3.6	6.7	2.0	7.3	4.0	10.3	21.3	6.7	15.0	33.6	14.3
	5	6.3	9.3	6.7	6.7	2.3	6.0	5.3	2.3	6.3	2.4	1.6	2.0	9.7	10.6	6.3	13.7	19.3	14.7
	6	5.3	15.3	6.3	3.0	1.0	5.0	4.3	2.3	6.0	0.7	1.0	2.3	12.0	11.3	5.7	15.3	21.0	13.3
	7	4.0	10.6	2.3	4.0	2.3	5.3	0.0	2.0	6.7	3.6	2.9	4.3	10.3	14.0	6.7	14.3	23.6	13.3
	Mean	6.9	11.3	5.4	5.8	4.0	5.4	3.8	3.1	6.7	2.2	5.1	3.0	11.7	15.2	6.0	16.7	25.7	13.6

6.4. Development of Alternative Storage Containers

Because of the importance of insect problems in stored grain and potential long-term risks (human health, insect resistance) of continual dependence on synthetic chemical insecticides, the possibilities offered by small airtight containers in Rwanda should be further investigated. At the same time, improved methods of insect monitoring should be developed. Rwandans have also expressed the need for more durable farm-level storage structures, a characteristic also embodied in the airtight containers (metal and plastic drums) under test.

In addition, two prototype 'airtight' metal containers were designed and built in Kigali in early 1987 (see Appendix B for description and design features). They were developed in an effort to improve on the used oil drum. Though more expensive, they were built with locally available materials and are intended to be sturdier, longer lasting (10-20 years), more airtight and easier to empty than the oil drum. They were also designed for easy fumigation and for use in conserving seed stocks by research stations, rural development projects, cooperative groups and others. These kinds of structures are less suitable for short-term storage and situations where the container must be opened frequently to meet family food needs. They are more applicable for longer term storage of crop surpluses and late season food supplies.

It is unlikely that research can make significant improvements in the design and construction of traditional baskets which have evolved over the centuries. They may further improve in the future as in the past, due to the ingenuity and creativity of thousands of local artisan builders and the farmers themselves. Researchers in collaboration with extension personnel can facilitate that process by traveling widely, observing, and disseminating information about numerous structural variants that exist and will arise. But research efforts will probably best be spent in designing and testing new containers and not redesigning traditional ones. One possible exception to this approach is research aimed at rodent-proofing baskets and granaries for those situations where rats and mice are considered a serious problem by farmers.

It is therefore recommended that studies of these alternative storage containers be pursued to determine more precisely their effectiveness in controlling insect infestations and in maintaining certain quality attributes such as germinability, bean cookability, and bean coloration. Specifically, it is suggested that a second experiment be conducted, but with more focused objectives and on a more limited scale in order to avoid some of the logisitical problems experienced in the first study. The following variables appear now to be the most important.

(1) Container type:

- used metal oil drum (checked and repaired for holes)
- new metal storage container
- medium or large basket (uncovered) as a control and representative of traditional containers
- 'imboho' (optional but suggested because of promising performance in first experiment)

(2) Initial grain moisture content:

- lower (12-13% mc)
- higher (15-16% mc)

(3) Insect treatment:

- grain treated with Actellic according to recommended rates and methods
- grain not treated with any insecticidal preparation

(4) Infestation level (lower priority and dependent on logistical feasibility):

- low (5 insects/kg of grain)
- high (50 insects/kg of grain)

Because of the inherent variability in this kind of experiment, replication is especially important. A minimum of three replicates is recommended but will depend on what is practical and feasible at the time. The experimental protocol should be finalized by those who will conduct the research; the comments here are presented simply as suggested guidelines.

It is probably advisable to limit this study to one commodity and to give priority to beans. Some preliminary, small-scale studies could be run simultaneously on sorghum and/or maize (the same variables cited above should be examined).

For beans, it is recommended to use fresh (recent harvest), non-treated, high quality (low levels of damaged grain and foreign material) varietal mixtures obtained directly from producers. Producer deliveries to OPROVIA at Kicukiro or another location are a possible source. Thorough blending and rigorous representative sampling procedures are, of course, important to minimize variability. For the same reason, close attention to laboratory analysis methods is critical. The final sampling at the conclusion of the experiment (6-12 months depending on the goal) might best be accomplished by removing the entire contents of each container, then mixing, quartering, and sampling (see Harris and Lindblad, 1978).

6.5. Summary and Conclusions

Considerable variability in the results does not allow firm conclusions to be drawn. The most consistent result was the change in moisture content during storage in the traditional containers compared to the constant moisture content maintained by the alternative, airtight containers (metal and plastic drums). These containers were tight enough to limit moisture exchange with the external environment although not tight enough to provide an environment to kill all insects in all cases.

While the alternative containers may offer some advantages for storage, they could create some additional problems for producers in managing storage. Producers need to be made aware of the importance of drying beans to lower moisture contents (<13% mc) before they are put in these kinds of containers. The loss in moisture with traditional containers suggests that producers may be realizing the advantage of some additional drying during storage--especially for beans that are put into containers at a higher moisture content. If higher moisture content beans are put into a container that does not allow drying, problems of increased hardness, increased mold damage and decreased germination could result. Particularly low germination was observed for the 16.5% mc beans put in the metal and plastic containers in this study, but decreases in germinability of beans stored at 13% mc or less were roughly similar for all containers. Instrumental hardness and percent hard-to-cook were not greater for the metal and plastic containers at 16.5% mc moisture content than for other containers in this study; however, generally high levels of hardness may have obscured this result.

The results show that insecticide treatments are not always 100% effective. This underscores the need for regular monitoring of insect pests to detect control failures or new infestations. Improved procedures for using insecticides should also be developed. Research emphasis in the immediate future should be placed on testing alternative containers rather than on modifying traditional structures with the exception of design changes related to rodent-proofing.

7. UNDERGROUND STORAGE

Grain has been stored underground in many parts of the world, especially in the Middle East, Africa, China and India (Dunkel, 1985). Sealed storage pits have been a very important part of the farming system in those regions for many centuries. Providing there is a sufficient depth of workable soil, underground pits are easy and inexpensive to construct. They are most useful for and have mainly been developed in dry areas where wood and plant material suitable for making other types of storage structures are in short supply (Gilman and Boxall, 1974). Where pits are hidden, it has served farmers also as a way of avoiding theft of the grain (Lindblad & Durben, 1977). In Brazil, underground plastic-lined silos have been demonstrated to offer a simple, efficient and inexpensive way of storing maize and dry beans at the farm level (Sartori, 1986).

The key to successful underground storage is to restrict the flow of air and moisture from the surrounding soil into the stored product. The main environmental advantage of locating a sealed storage underground are twofold: more constant and uniform temperatures and a low oxygen atmosphere within the storage pit (Sterling et al., 1983). Stable and uniform temperatures are desirable for controlling moisture migration within the grain mass and condensation in the vicinity of the pit walls. When oxygen replenishment is prevented by airtight storage conditions, the respiration of the grain, insects and fungi diminishes the available oxygen within the storage pit to such low levels that most insects and fungi cannot survive. This may eliminate the need for some expensive insecticidal and fungicidal treatments. When the grain is stored under dry conditions, the development of anaerobic bacteria does not take place. At the same time, storage pits effectively prevent the entry of storage insects, rodents and birds.

There is no evidence that underground storage was ever practiced in Rwanda. Because of the results obtained in other countries, it was decided to evaluate this concept under the Rwandan conditions. In a first experiment dry, high quality beans were stored underground for one year. After it was established that this method could be applied successfullly under the local conditions, a second experiment was started to evaluate its applicability for storing higher moisture and insect infested beans.

7.2. First Underground Storage Experiment

7.2.1. Methodology

The site selected for this study is located on a flat piece of grassland next to the OPROVIA/GRENARWA offices in Kicukiro. The soil texture is of a heavy clay type and has a high moisture retention. The soil profile does not show much differentiation down to a depth of at least 1.75 m but contains quartz rock debris throughout. The groundwater table is at a depth of more than

5 m all year round. Annual rainfall exceeds 1250 mm and is mostly spread over two rainy seasons (March-May and September-December).

In early October 1985, three pits (Fig. 7.1) with a length of 2.25 m, a width of 1.70 m and a depth of 1.50 m were hand dug. Sharp objects such as rocks and roots were removed from the pit walls and floor. The bottom was covered with a 0.15 m thick layer of coarse sand. Two 0.1 mm thick plastic sheets, 3.00 m wide and 5.00 m long, were placed crosswise on top of the sand layer. In each pit eight woven plastic bags (non-airtight), each containing 90 kg of dry beans were stacked in three layers. It was decided to use bags instead of bulk storage for ease of handling during filling and emptying of the pits. The woven bags had a rated capacity of 100 kg. By underfilling the bags the air space in between stacked bags and the initially avaliable oxygen supply were reduced considerably. Each bag was numbered and instrumented with a type-T (copper-constantan) thermocouple. The thermocouple wires were bundled and extended above ground level. The two plastic sheets were then one by one wrapped around the bag pile to form an envelope. The envelope was sealed with duct tape.

The spaces left between the pit walls and the bag pile were filled with sand. Also a 0.10 m layer of sand was placed on top of the pile, so that the envelope was completely surrounded by sand. This sand layer provides a protective cushioning for the plastic envelope and some moisture protection as well as drainage. Water will not enter the sand layer unless the surrounding soil is competely saturated. An added advantage may be that it forms a natural barrier against termites, who prefer to build their nests in the heavier clay soils. The remainder of the pit was filled and the pit area was slightly mounded with the excavated soil. Finally, each pit was covered with a 6.00 x 6.00 m plastic tarp which in turn was covered and held in place with a 0.15 m thick layer of excavated soil. No further precautions were taken to prevent moisture infiltration into the storage pit. The incorporation of a sand layer in this design is not considered absolutely necessary to obtain a successful underground storage pit, as long as the envelope is air and moisture proof.

For this study 2,160 kg of beans were obtained in the Rusumo area. Mixing several bean varieties in the field is a very common practice in Rwanda. This particular lot contained fifteen varieties and represented a varietal mixture typical for the southeastern part of the country. The beans were selected from this location because of their relatively low moisture content (approximately 13%) and apparently good physical quality, characteristics considered desirable for long-term storage. The beans were grown on numerous small farms and harvested in July, 1985, at the onset of the dry season. They were naturally air-dried on the farms before being sold to the local cooperative, where they were stored for about three months under excellent conditions. The only insecticidal treatment was a Phostoxin fumigation during August.

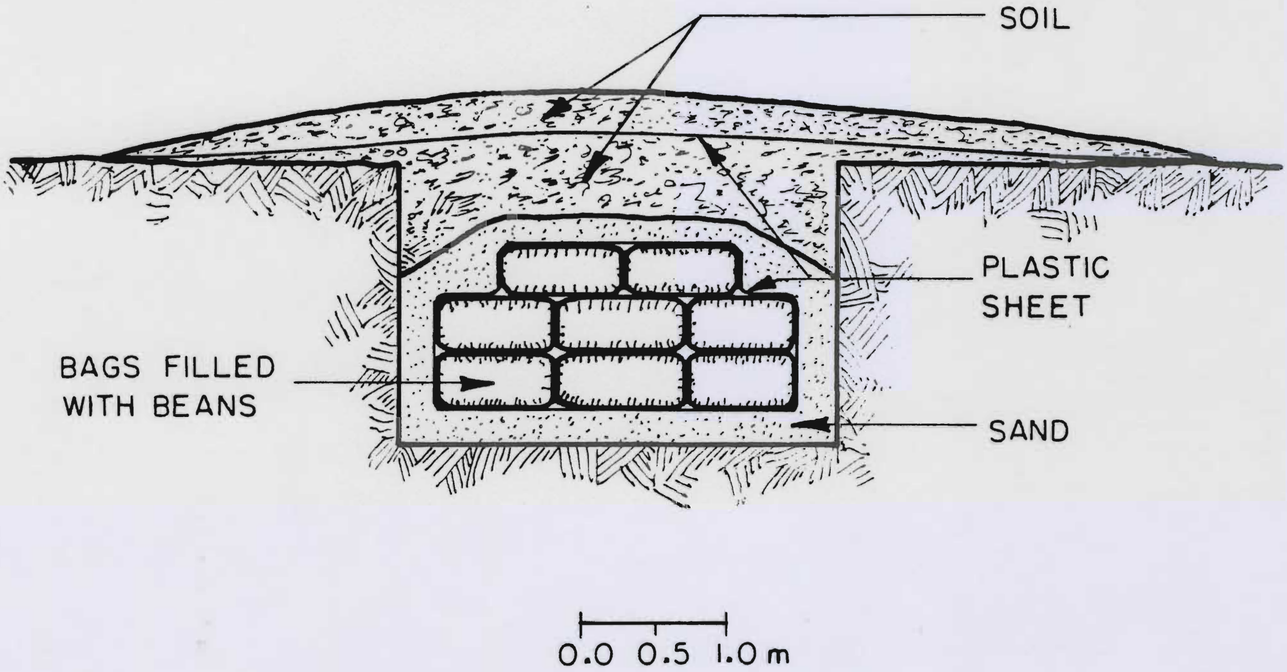


Figure 7.1. Underground storage pit--cross-sectional view.

Just before bagging and placing the beans in underground storage, six samples each weighing about 1.0 kg were drawn at random from the total batch. These samples were analyzed in the Grain Quality Laboratories of OPROVIA to evaluate the hardness and physical quality characteristics of the bean stock. The quality factors measured were test weight, moisture content, foreign material, the presence of insects and the percentage beans damaged by insects and molds. The three pits were filled on October 10, 12 and 14, 1985. The temperature in each bag was measured on a weekly basis with a Cole Parmer type-T thermocouple thermometer (model 8110-25). At the same time soil temperatures were measured at depths of 0.05, 0.10, 0.25, 0.50, 0.75 and 1.00 m. Comparing the temperature within the bags to the surrounding soil temperatures indicates the level of biological activity within the grain mass. Incipient spoilage and heavy insect infestations are always accompanied by a substantial rise in temperature. Every four months one of the pits was emptied, and each bag was sampled for a complete analysis.

7.2.2. Results and Discussion

Soil temperatures at a depth of 0.50 m and below (Fig. 7.2) remained faily constant throughout the 12 month observation period. The average soil temperature occurring in the zone between 0.50 and 1.00 m below the surface was 22.6°C. The seasonal variations were limited to within the 20.8 - 23.8°C range. At a depth of 0.05 m the soil temperature fluctuated daily between 19.0 and 25.0°C. Meanwhile the temperatures within the three pits (Fig. 7.2) remained stable and very uniform. The average temperature for the entire storage period within each pit was 23.6, 23.5 and 23.7° C respectively. In general these temperatures are considered favorable for the development of insects and the hardening of beans. It can be seen from the graphs that the pit temperatures follow closely the soil temperatures. The average pit temperature is 1.0°C higher than the average soil temperature. This small difference indicates that the biological activities in the stored grain mass (respiration of beans, insects, fungi) took place at a low level only.

The results of this experiment show that the overall bean quality was well maintained after 15 months in underground storage. A comparison of the measured physical quality and cookability characteristics of the beans before and after 4, 8 and 12 months of storage is given in Table 7.1. After four months the moisture content of the beans in the first pit increased by 0.25%. However, this trend did not continue in the other two pits. When emptying the pits, it was observed that the soil around the pit was moist, but not saturated. Also the sand around the plastic envelope was found to be damp, but condensation was never found inside the plastic envelopes or in any of the bags. Since there were no visible signs of moisture leakage in any of the pits, it was hypothesized that the observed increase in moisture content in the first pit, although statistically highly significant ($P<0.001$), was due only to variability within the initial bean batch. The plastic tarps covering the pit areas were torn in several places. As such

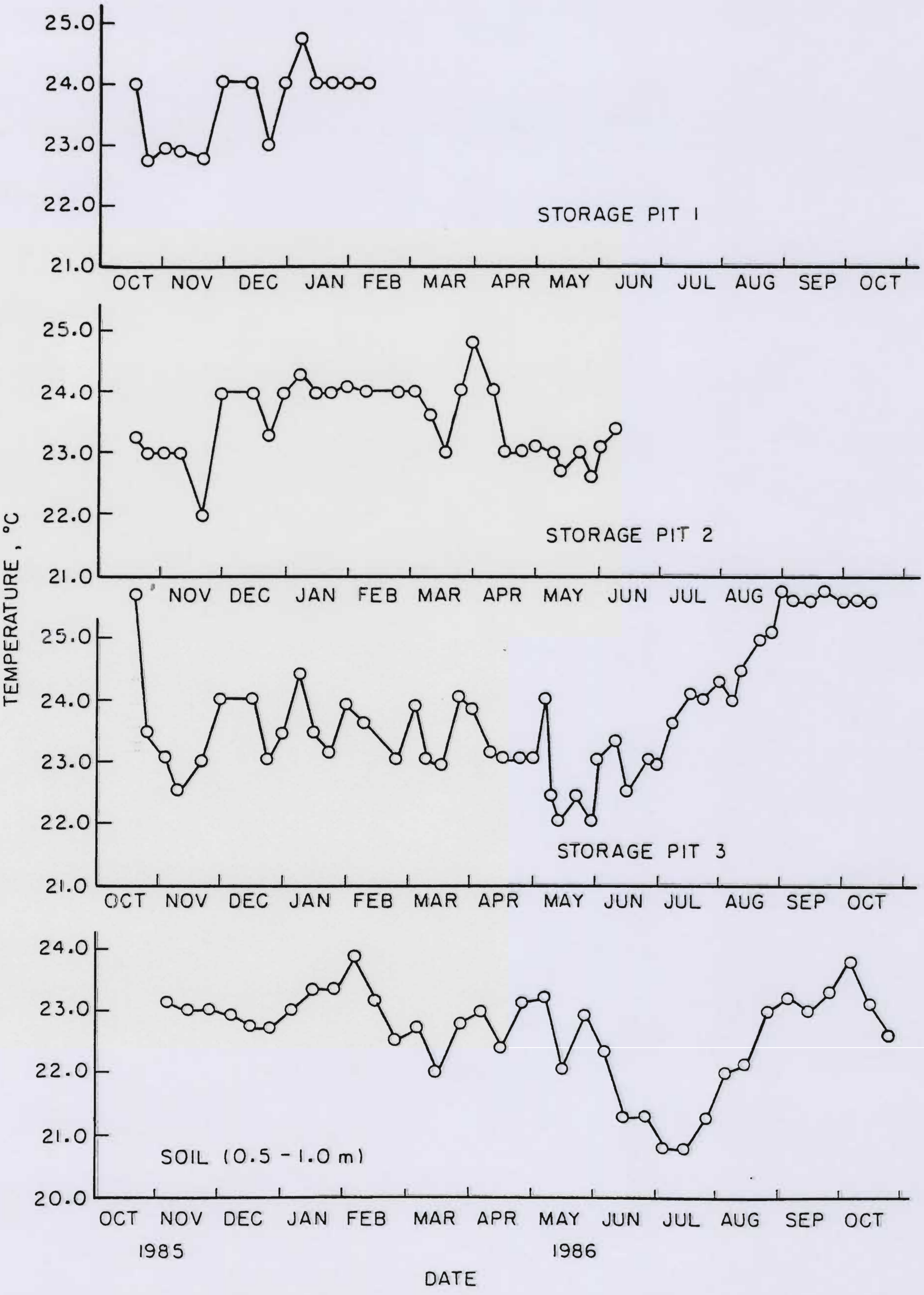


Figure 7.2. Mean temperatures observed in three storage pits filled with beans and mean soil temperatures for the first underground experiment (October 1985-October 1986).

Table 7.1. Changes in quality of Rwandan beans from the first underground storage experiment (Twenty four 90 kg. bags).

Time (Months)		Moisture Content (%)	Test Weight (kg/m^3)	Total Insects per kg.	For. Mat. (%)	Storage Damage					In-edible (%)	Un-plant. (%)	Mean Hardness (Newton)	Hard-to-cook (%)	Temp (°C)	Germ. (%)
						Insect (%)	Mold (%)	Rodent (%)	Germin. (%)	Total (%)						
0	A	13.1	757.4	0.00	0.83	0.0	0.0	0.0	0.0	0.0	4.3	11.0	3.20	23.0	-	-
	B	13.1	757.1	1.20	1.14	0.0	0.7	0.0	0.3	1.0	6.0	12.7	2.73	11.0	-	-
	C	13.0	754.4	1.20	1.12	0.0	0.3	0.0	0.0	0.3	8.3	15.0	3.16	26.0	-	-
	D	13.0	756.9	0.00	0.82	0.0	0.3	0.0	0.0	0.3	7.7	17.7	2.80	17.0	-	-
	E	12.9	754.9	0.00	0.84	0.0	0.0	0.0	0.0	0.0	7.3	16.0	3.07	21.0	-	-
	F	13.0	752.0	0.00	0.98	0.0	1.3	0.0	0.3	1.6	8.9	16.7	2.65	14.0	-	-
	Mean	13.0	755.5	0.40	0.96	0.0	0.4	0.0	0.1	0.5	7.1	14.9	2.93	18.7	-	-
4	1	13.3	754.8	1.20	1.21	0.0	0.0	0.3	0.0	0.3	9.3	18.3	3.62	28.0	23.6	-
	2	13.3	764.0	0.00	0.81	0.0	0.0	0.0	0.0	0.0	8.7	15.3	3.25	25.0	-	-
	3	13.2	759.8	0.00	0.81	0.0	0.0	0.0	0.3	0.3	12.7	22.0	2.94	13.0	23.6	-
	4	13.3	765.8	0.00	0.53	0.3	0.0	0.0	0.0	0.3	13.7	25.3	3.44	23.0	23.5	-
	5	13.4	756.4	0.00	0.43	0.7	0.0	0.0	0.0	0.7	9.7	21.3	3.74	42.0	23.7	-
	6	13.1	753.8	0.00	1.19	0.3	0.7	0.0	0.0	1.0	9.7	18.7	3.30	24.0	23.6	-
	7	13.3	760.8	0.00	0.80	1.0	0.0	0.0	0.3	1.3	9.7	18.7	3.39	18.0	23.7	-
	8	13.3	755.8	0.00	0.64	0.3	0.3	0.0	0.0	0.6	11.7	22.0	3.76	32.0	23.6	-
	Mean	13.3	758.9	0.20	0.80	0.3	0.1	0.0	0.1	0.6	10.7	20.2	3.43	25.6	23.6	-
8	9	13.0	749.9	2.42	0.76	0.0	0.0	0.3	0.3	0.6	15.7	19.0	3.10	25.0	23.4	89.5
	10	13.2	754.0	1.20	0.47	0.3	0.0	0.3	0.0	0.6	14.3	21.7	3.52	36.0	23.5	68.5
	11	12.9	743.1	0.00	0.50	0.0	0.0	0.0	0.0	0.0	13.0	19.3	3.79	43.0	23.5	84.0
	12	13.0	754.0	0.00	0.29	0.3	0.3	0.3	0.0	0.9	13.3	19.3	3.59	41.0	23.4	74.5
	13	13.2	752.6	0.00	0.32	0.3	0.0	0.0	0.0	0.3	13.7	22.7	3.19	16.0	23.4	-
	14	13.0	752.6	0.00	0.25	0.0	0.0	0.3	0.0	0.3	13.7	21.0	3.18	16.0	23.5	58.0
	15	13.1	750.6	0.00	0.56	0.0	0.0	0.0	0.0	0.0	19.7	25.3	3.17	15.0	23.5	-
	16	13.2	749.7	1.21	0.62	0.0	0.0	0.0	0.0	0.0	17.3	23.0	3.24	18.0	-	81.0
	Mean	13.1	750.8	0.60	0.47	0.1	0.0	0.2	0.0	0.3	15.1	21.4	3.35	26.3	23.5	75.9
12	17	13.1	745.8	0.00	0.41	0.0	0.3	0.0	0.0	0.3	8.7	12.7	3.49	27.0	23.4	82.5
	18	13.1	750.7	1.21	0.76	0.0	0.0	0.7	0.0	0.7	8.7	12.8	3.63	38.0	23.6	75.5
	19	13.1	757.4	0.00	0.91	0.3	0.0	0.0	0.3	0.6	10.3	14.0	3.54	30.0	23.7	80.0
	20	12.9	747.5	3.64	0.77	0.3	0.0	0.3	0.0	0.6	7.7	12.1	3.42	26.0	23.7	77.0
	21	12.9	766.9	2.37	0.59	0.3	0.0	0.0	0.3	0.6	8.3	13.7	3.49	30.0	23.8	88.0
	22	13.0	751.6	0.00	0.58	0.7	0.0	0.0	0.3	1.0	10.0	16.0	3.44	29.0	23.9	59.5
	23	12.7	756.4	1.20	1.87	0.7	0.3	0.7	0.4	2.1	8.7	15.7	3.33	24.0	23.7	61.0
	24	12.7	747.7	2.43	0.75	0.0	0.3	0.0	0.0	0.3	9.0	13.3	3.43	33.0	24.0	80.0
	Mean	12.9	753.0	1.36	0.83	0.3	0.1	0.2	0.2	0.8	8.9	13.8	3.47	29.6	23.7	75.4

they did not prove to be a useful barrier against moisture infiltration.

The number of insects found per kilogram of grain did not change significantly ($P<0.05$) over time. All insects found were dead specimens. Extensive incubation tests also never revealed the presence of live insects. It is therefore assumed that the insects found were killed during the Phostoxin treatment, so that the beans used for this experiment were either free of live insects or that young larvae subsequently died upon emergence as adults. Thus the apparent differences do not represent any real increase in the insect population. None of the other physical quality factors, i.e. test weight, percent foreign material, percent insect damaged and visibly moldy beans changed significantly ($P<0.05$) during the test period.

After 12 months of storage the bean hardness and percent hard-to-cook beans increased by 0.67 Newton (from 2.87 to 3.54 Newton) and 6.9% (from 18.7 to 29.5%), respectively. Although these changes are statistically significant ($P<0.01$), much larger increases have been measured in above ground storages in Rwanda. A trained sensory hardness panel would normally not detect differences in hardness of less than 0.50-1.0 Newton. A sample is generally considered acceptable when it contains less than 25-30% hard-to-cook beans and has a mean hardness of less than 3.60 Newton. Neither of these thresholds were exceeded after 12 months of underground storage. When opening the plastic envelopes no off-odors were observed. Bystanders noticed the natural brightness of the beans colors had not faded, even after 12 months in underground storage. The low oxygen environment is probably responsible for slowing down the biochemical aging processes. Bean germination remained high after 12 months of storage.

7.3. Second Underground Storage Experiment

The previous study has shown that dry edible beans can be safely stored underground for at least one year, provided they have a low initial moisture content (e.g. 13%), are protected from soil moisture, and are free of insects. In practice, however, some of these conditions are not always easily obtained. The climatic conditions during the months following the traditional harvest seasons are such that it requires skillful management to lower the moisture content of beans to around 13% with natural air drying methods only. The initial infestation of beans by bruchids often begins in the field prior to harvest. Because of these circumstances, additional research was conducted using insect-infested, higher moisture beans to determine if they could be safely stored underground, without incurring the costs and safety hazards of insecticidal treatments and artifical drying.

7.3.1. Methodology

During the second week of May 1986, six underground pits were each filled with 11 bags of 90 kg of untreated beans each. The pit configuration and the techniques used to seal the plastic envelopes were identical to those used in the first underground storage experiment. The beans were part of the large batch purchased for the cooperative silo aeration experiment in Kanama and Rusatira. After they were purchased and before they were placed in underground storage, they were kept in a small bag pile on pallets in the OPROVIA warehouse in Kicukiro. No insecticides were applied. During this period insects proliferated throughout the stack. In early May, the beans were run through a Clipper seed cleaner to take out most of the live insects (adults) and foreign material. The beans were then placed in bags filled to a standard weight of 90 kg. During this filling operation each bag was sampled for a complete quality analysis. As soon as 11 bags were ready, they were placed in an underground storage pit as described above. Each bag was equipped with a thermocouple for temperature monitoring. Every four months one of the pits is opened for a destructive sampling. The first two were opened on September 9, 1986 and January 21, 1987, respectively.

7.3.2. Results and Discussion

Tables 7.2-7.5 show the results of the quality analysis. Results are presented by storage period and bag number. Tables 7.2 and 7.3 contain the results for initial samplings of bag numbers 34-66 and the final results from the pits opened after 4 months (bag numbers 56-66) and 8 months (bag numbers 45-55) of storage. The pit containing bag numbers 34-44 will be opened in May 1987 after 12 months of storage. Tables 7.4 and 7.5 contain the results for the initial samplings of bag numbers 1-33 which will be opened at 16, 20 and 24 months of storage.

The beans had an average initial moisture content of 13.8% and contained 12.7 live bruchids per kg of seeds (Tables 7.2 and 7.4). The incubation results also showed a high degree of infestation. The percent hard-to-cook was initially 27.3 with a mean instrumental hardness of 3.32 Newtons. Germination was initially 58%.

The initial level of insect damaged beans (Tables 7.3 and 7.5) averaged 10.5% which is consistent with the high initial insect levels. Initially, discolored beans averaged 7.1%. Inedible and unplantable beans initially averaged 25.1% and 33.9%, respectively.

After 4 and 8 months of storage, moisture content remained essentially constant (Table 7.2). No live insects were found (Table 7.2) which indicates that an airtight environment was created which effectively killed the insects.

Table 7.2. Changes in quality (moisture content...germination) of Rwandan beans stored for 4, 8 and 12 months (bag numbers 34-66) in the second underground experiment. I - beginning of experiment (0 months); II - at opening of pit (either 4, 8 or 12 months).

		Moisture Content (%)		Test Weight (kg/m^3)		Foreign Mat. (%)		Total Insects per kg.		Live Insects per kg.		Incubation (0 months)		Mean Hardness (Newton)		Hard-to-cook (%)		Germination (%)	
Months	Bag #	I	II	I	II	I	II	I	II	I	II	Live	Dead	I	II	I	II	I	II
4	66	13.8	13.9	711.1	710.7	0.08	0.10	39.6	6.4	5.1	0.0	0	14	3.40	3.54	30	31	68.5	44.0
	65	13.6	13.9	710.1	705.8	0.05	0.04	40.9	19.3	2.6	0.0	0	15	3.13	3.64	25	32	79.5	34.5
	64	13.7	13.8	708.3	706.8	0.01	0.05	34.6	16.7	1.3	0.0	0	21	3.36	3.91	33	47	74.0	56.0
	63	13.7	13.9	708.3	711.5	0.05	0.23	12.8	2.6	5.1	0.0	0	14	2.93	3.66	17	41	69.0	12.5
	62	13.3	13.7	711.9	710.7	0.08	0.04	48.5	2.6	8.9	0.0	0	2	3.29	3.55	26	30	70.5	41.0
	61	13.7	13.6	715.3	713.1	0.01	0.05	53.3	0.0	10.2	0.0	0	51	3.48	3.24	30	29	80.5	50.5
	60	13.4	13.7	708.1	712.5	0.01	0.03	57.7	3.8	0.0	0.0	0	13	3.39	3.30	21	24	68.0	49.5
	59	13.7	13.7	712.8	711.4	0.08	0.04	66.3	0.0	11.5	0.0	0	65	3.28	3.25	16	27	77.5	47.5
	58	13.6	13.9	713.9	713.8	0.01	0.11	52.2	39.4	6.4	0.0	0	24	3.65	3.11	30	18	64.0	53.0
	57	13.7	13.7	725.7	710.7	0.08	0.08	87.6	11.5	7.5	0.0	0	76	3.58	3.15	35	22	77.5	54.0
	56	13.2	13.8	711.6	708.2	0.06	0.09	29.4	0.0	5.1	0.0	0	4	3.13	3.24	24	23	82.0	49.0
	Mean	13.6	13.8	712.5	710.5	0.05	0.08	47.5	9.3	5.8	0.0	0	27	3.33	3.42	26	29	73.7	44.7
8	55	13.6	13.8	714.0	684.4	0.03	0.15	22.9	9.3	5.1	0.0	0	56	3.09	3.74	26	38	63.0	27.5
	54	13.5	13.9	712.9	709.6	0.04	0.18	63.7	11.5	6.4	0.0	0	15	3.28	3.65	28	33	69.0	12.0
	53	13.5	14.0	712.6	698.4	0.03	0.12	43.3	18.2	14.0	0.0	0	6	2.95	4.08	15	50	64.0	24.0
	52	13.8	13.7	719.7	710.1	0.10	0.09	46.7	7.7	6.3	0.0	0	18	2.79	3.96	13	31	49.0	35.5
	51	13.6	14.1	714.0	704.3	0.05	0.15	36.9	52.9	3.8	0.0	0	7	3.39	4.06	36	38	72.0	30.0
	50	13.8	13.9	713.5	711.2	0.04	0.04	58.5	25.5	5.1	0.0	0	12	3.20	3.67	25	36	59.5	18.0
	49	14.1	13.9	709.2	708.2	0.05	0.27	39.7	19.2	3.8	0.0	0	7	2.91	3.93	18	36	69.5	28.0
	48	13.6	13.5	711.6	700.6	0.06	0.16	66.4	31.1	16.6	0.0	0	26	3.51	3.90	27	46	59.5	27.0
	47	13.7	13.6	718.3	714.5	0.08	0.10	73.3	11.4	7.6	0.0	0	60	3.09	3.81	24	44	61.5	25.0
	46	13.8	14.0	712.7	712.0	0.09	0.15	40.8	16.6	3.8	0.0	0	8	3.45	3.77	29	44	43.0	22.0
	45	13.8	14.0	715.2	706.4	0.01	0.23	47.0	21.9	5.1	0.0	1	10	3.24	3.74	20	39	74.0	23.5
	Mean	13.7	13.9	714.0	705.4	0.05	0.15	49.0	20.5	7.1	0.0	0	20	3.17	3.85	24	40	62.2	24.8
12	44	13.5	-	710.7	-	0.01	-	25.6	-	6.4	-	0	13	3.22	-	21	-	43.5	-
	43	13.7	-	717.9	-	0.03	-	62.0	-	10.1	-	0	45	3.46	-	25	-	67.0	-
	42	13.6	-	710.5	-	0.15	-	17.9	-	12.8	-	0	11	3.40	-	28	-	61.0	-
	41	13.7	-	723.8	-	0.03	-	53.9	-	7.5	-	0	52	3.29	-	34	-	64.5	-
	40	13.4	-	715.9	-	0.03	-	68.5	-	3.8	-	0	6	3.32	-	28	-	45.0	-
	39	13.3	-	714.0	-	0.06	-	47.1	-	12.7	-	0	9	3.36	-	35	-	61.5	-
	38	13.2	-	717.2	-	0.08	-	39.3	-	6.3	-	0	1	3.27	-	23	-	50.0	-
	37	13.7	-	728.7	-	0.04	-	58.6	-	12.5	-	0	12	3.69	-	33	-	53.5	-
	36	13.9	-	719.2	-	0.04	-	32.8	-	7.6	-	0	17	3.42	-	29	-	54.0	-
	35	13.7	-	715.7	-	0.05	-	41.9	-	7.6	-	0	4	3.32	-	28	-	43.0	-
	34	13.2	-	708.3	-	0.12	-	39.7	-	2.6	-	0	6	3.23	-	22	-	46.0	-
	Mean	13.5	-	716.5	-	0.06	-	44.3	-	8.2	-	0	16	3.36	-	28	-	53.5	-

Table 7.3. Changes in damage (insect...unplantable) of Rwandan beans stored for 4, 8 and 12 months (bag numbers 34-66) in the second underground experiment. I - beginning of experiment (0 months); II - at opening of pit (either 4, 8 or 12 months).

		Storage Related Damage										Broken (%)		Discolored (%)		Torn Pericarp (%)		Small (%)		Wrinkled (%)		Dented (%)		Inedible (%)		Unplantable (%)	
		Insect (%)		Mold (%)		Rodent (%)		Germinated (%)		Total (%)																	
Months	Bag #	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
4	66	13.7	12.7	2.7	5.3	0.0	0.0	0.0	0.0	16.4	18.0	1.7	2.7	6.3	11.3	0.3	3.7	7.0	7.3	4.0	5.0	6.7	7.7	24.3	28.0	36.3	36.0
	65	10.7	12.0	3.0	6.0	0.0	0.0	0.3	0.0	14.0	18.0	0.7	0.7	7.7	11.0	1.3	3.0	10.3	6.3	5.0	3.3	4.0	9.7	26.0	27.3	32.0	34.7
	64	9.7	12.7	2.0	6.0	0.0	0.0	0.3	0.7	12.0	19.4	0.0	1.0	6.7	11.0	1.0	1.3	10.7	10.3	4.3	3.0	3.0	6.7	29.7	31.0	23.7	37.7
	63	11.0	14.7	3.0	4.7	0.0	0.0	0.3	0.0	14.3	19.4	1.3	2.0	7.3	11.7	0.0	2.7	8.7	5.0	4.3	3.7	4.3	9.3	25.0	24.0	32.7	35.3
	62	7.7	14.3	2.0	9.3	0.3	0.0	0.3	0.0	10.3	23.6	2.0	0.3	6.3	12.0	1.0	1.0	8.3	6.3	6.0	2.3	5.3	5.3	20.0	30.7	29.7	40.0
	61	9.7	13.3	1.3	7.3	0.3	0.0	0.0	0.0	11.3	20.6	1.0	0.3	6.0	11.3	2.3	1.7	8.7	6.3	6.0	5.3	4.0	10.0	22.7	24.3	32.7	34.7
	60	16.7	19.0	3.3	6.3	0.0	0.0	0.0	0.0	20.0	25.3	3.3	1.7	7.7	10.3	0.7	3.0	9.3	5.7	3.7	4.0	3.0	7.3	24.7	32.7	33.3	39.0
	59	10.0	19.3	1.0	6.3	0.0	0.0	0.0	0.0	11.0	25.6	0.7	2.3	7.0	9.3	5.0	1.0	7.0	7.7	4.0	2.7	6.3	9.3	21.3	33.0	34.3	43.0
	58	10.0	19.0	2.3	8.7	0.0	0.3	0.0	0.3	12.3	28.3	2.7	0.3	6.0	10.3	0.7	3.0	7.0	6.0	6.0	3.0	4.0	8.0	20.3	33.3	30.3	40.7
	57	12.7	15.0	1.0	6.7	0.0	0.0	0.0	0.7	13.7	22.4	2.3	0.7	7.7	11.0	2.0	1.7	9.0	6.7	7.0	2.7	7.7	6.7	29.3	29.3	37.3	39.3
	56	10.3	15.0	1.0	4.3	0.0	0.0	0.0	0.0	11.3	19.3	2.3	2.7	9.0	12.0	1.3	1.3	7.0	6.0	5.7	3.0	8.0	9.0	29.0	26.3	37.0	35.3
	Mean	11.1	15.2	2.1	6.4	0.1	0.0	0.1	0.2	13.3	21.8	1.6	1.3	7.1	11.0	1.4	2.1	8.5	6.7	5.1	3.5	5.1	8.1	24.8	29.1	32.7	37.8
8	55	7.3	17.3	1.3	5.3	0.0	0.0	0.0	0.0	8.6	22.6	2.0	1.0	6.7	25.0	1.3	1.3	6.7	7.3	5.7	5.7	7.3	7.3	19.3	25.0	27.0	33.7
	54	9.0	11.7	2.0	4.0	0.0	1.0	0.3	0.0	11.3	16.7	0.3	1.3	7.3	33.0	1.0	2.7	5.3	12.0	7.3	5.3	8.0	6.7	27.7	21.3	33.3	34.3
	53	9.7	9.7	2.0	7.7	0.0	0.7	0.0	0.0	11.7	18.1	1.3	1.0	6.7	19.0	2.3	2.7	8.7	5.0	6.3	4.7	9.3	11.3	26.7	19.7	35.0	27.0
	52	11.7	9.0	2.0	5.7	0.0	0.3	0.0	0.3	13.7	15.3	1.3	1.0	9.0	26.3	1.3	3.7	7.3	14.3	6.3	2.0	9.7	5.0	27.7	19.7	36.3	28.0
	51	9.7	10.3	3.3	4.7	0.3	0.0	0.0	0.7	13.3	15.7	2.0	0.7	7.3	26.7	0.0	0.7	8.7	9.7	6.3	5.7	10.7	4.3	30.7	18.0	40.7	29.0
	50	10.0	15.3	2.0	4.0	0.3	0.0	0.0	0.0	12.3	19.3	2.0	0.3	5.7	35.3	0.7	1.0	5.7	9.0	5.7	3.7	3.0	3.7	20.0	20.0	29.3	33.3
	49	9.7	13.7	2.7	6.3	0.0	1.0	0.0	0.0	12.4	21.0	2.3	1.7	6.3	24.0	0.0	3.7	8.0	4.7	6.3	5.7	11.0	3.0	30.0	22.0	41.0	29.0
	48	7.3	9.7	2.3	3.3	0.0	0.0	0.0	0.3	9.6	13.3	0.7	1.3	8.3	22.3	4.3	2.3	3.0	8.0	6.7	5.7	10.0	12.7	21.0	18.7	33.3	30.0
	47	9.7	8.7	1.3	6.3	0.0	0.3	0.0	0.0	11.0	15.3	2.7	0.7	8.3	28.7	1.3	2.3	7.3	6.3	8.3	3.7	7.0	6.7	26.0	15.7	33.7	24.7
	46	8.7	14.0	2.0	9.0	0.0	0.0	0.3	0.7	11.0	23.7	1.7	1.0	7.2	28.7	0.7	3.0	5.7	10.0	6.7	2.7	8.3	3.7	27.0	22.3	33.3	33.7
	45	17.0	14.0	1.3	3.0	0.0	1.0	0.0	0.3	18.3	18.3	0.3	1.0	8.0	22.3	0.0	0.7	2.0	5.0	9.0	4.7	10.3	8.0	29.0	19.7	41.0	27.3
	Mean	10.0	12.1	2.0	5.4	0.1	0.4	0.1	0.2	12.1	18.1	1.5	1.0	7.3	26.5	1.2	2.2	6.2	8.3	6.8	4.5	8.6	6.6	25.9	20.2	34.9	30.0
12	44	14.0	-	2.0	-	0.0	-	0.0	-	16.0	-	0.0	-	8.0	-	0.7	-	4.3	-	8.0	-	9.3	-	28.3	-	39.0	-
	43	8.0	-	0.3	-	0.7	-	0.3	-	9.3	-	1.7	-	6.0	-	0.7	-	7.7	-	5.0	-	4.7	-	20.3	-	29.0	-
	42	14.7	-	1.0	-	0.0	-	0.0	-	15.7	-	1.0	-	10.0	-	2.7	-	9.3	-	9.3	-	10.0	-	33.3	-	45.3	-
	41	15.3	-	0.3	-	0.0	-	0.0	-	15.6	-	2.3	-	10.0	-	1.7	-	9.0	-	9.3	-	11.3	-	31.7	-	40.7	-
	40	10.7	-	0.7	-	0.0	-	0.0	-	11.4	-	2.3	-	0.3	-	1.3	-	8.3	-	4.7	-	6.0	-	18.7	-	28.7	-
	39	8.3	-	1.7	-	0.0	-	0.0	-	10.0	-	2.7	-	6.0	-	0.7	-	7.0	-	4.7	-	5.3	-	20.3	-	29.3	-
	38	11.0	-	0.3	-	0.0	-	0.0	-	11.3	-	2.7	-	10.0	-	1.3	-	7.3	-	9.3	-	8.3	-	30.7	-	39.0	-
	37	12.3	-	2.3	-	0.0	-	0.3	-	14.9	-	1.0	-	8.7	-	0.3	-	8.3	-	6.7	-	11.0	-	32.3	-	40.3	-
	36	6.3	-	1.7	-	0.0	-	0.0	-	8.0	-	2.7	-	9.7	-	1.3	-	8.7	-	7.3	-	9.0	-	23.0	-	31.3	-
	35	11.0	-	2.0	-	0.0	-	0.0	-	13.0	-	1.0	-	5.3	-	1.7	-	6.3	-	5.3	-	4.7	-	24.3	-	33.7	-
	34	11.3	-	1.7	-	0.0	-	0.3	-	13.3	-	1.3	-	6.3	-	1.3	-	9.3	-	6.0	-	6.0	-	26.0	-	34.7	-
	Mean	11.2	-	1.3	-	0.1	-	0.1	-	12.6	-	1.7	-	7.3	-	1.2	-	7.8	-	6.9	-	7.8	-	26.3	-	35.5	-

Table 7.4. Changes in quality (moisture content...germination) of Rwandan beans stored for 16, 20 and 24 months (bag numbers 1-33) in the second underground experiment. I - beginning of experiment (0 months); II - at opening of pit (either 16, 20 or 24 months).

		Moisture Content (%)		Test Weight (kg/m^3)		Foreign Mat. (%)		Total Insects per kg.		Live Insects per kg.		Incubation (0 months)		Mean Hardness (Newton)		Hard-to-cook (%)		Germination (%)	
Months	Bag #	I	II	I	II	I	II	I	II	I	II	Live	Dead	I	II	I	II	I	II
16	33	14.0	-	712.2	-	0.04	-	39.5	-	11.5	-	0	7	3.38	-	28	-	66.0	-
	32	13.6	-	711.0	-	0.11	-	34.5	-	2.6	-	0	8	3.50	-	25	-	55.0	-
	31	13.7	-	718.9	-	0.06	-	18.9	-	3.8	-	0	11	2.69	-	17	-	38.5	-
	30	14.0	-	704.1	-	0.01	-	81.2	-	28.4	-	0	8	3.01	-	21	-	31.5	-
	29	14.4	-	688.9	-	0.03	-	50.1	-	21.1	-	0	11	3.66	-	39	-	63.0	-
	28	13.9	-	706.0	-	0.03	-	64.3	-	14.1	-	0	4	3.56	-	41	-	36.0	-
	27	14.8	-	714.5	-	0.03	-	66.1	-	16.5	-	0	56	3.39	-	26	-	57.0	-
	26	14.6	-	729.7	-	0.02	-	78.4	-	13.7	-	0	70	3.59	-	39	-	42.5	-
	25	14.1	-	720.8	-	0.04	-	70.5	-	11.3	-	0	66	3.28	-	27	-	60.5	-
	24	14.2	-	711.4	-	0.06	-	40.8	-	8.9	-	0	5	3.24	-	26	-	52.5	-
	23	13.9	-	711.2	-	0.11	-	65.1	-	16.6	-	0	6	3.07	-	15	-	56.5	-
	Mean	14.1	-	711.7	-	0.05	-	55.4	-	13.5	-	0	23	3.31	-	28	-	50.8	-
20	22	13.7	-	713.0	-	0.09	-	67.5	-	5.1	-	10	9	3.39	-	32	-	49.0	-
	21	14.2	-	714.9	-	0.05	-	67.3	-	14.0	-	0	16	3.38	-	28	-	29.5	-
	20	13.7	-	708.6	-	0.01	-	80.7	-	16.7	-	0	72	2.96	-	12	-	59.5	-
	19	13.9	-	713.9	-	0.02	-	68.7	-	6.4	-	0	32	2.84	-	18	-	74.0	-
	18	14.2	-	716.4	-	0.03	-	46.9	-	7.6	-	0	4	3.14	-	24	-	39.5	-
	17	14.1	-	705.1	-	0.10	-	29.6	-	3.9	-	0	0	3.45	-	26	-	57.5	-
	16	13.9	-	712.9	-	0.08	-	38.2	-	20.4	-	0	13	3.45	-	26	-	61.0	-
	15	14.5	-	723.0	-	0.07	-	49.0	-	10.0	-	0	46	4.17	-	63	-	54.0	-
	14	13.8	-	713.7	-	0.01	-	31.8	-	8.9	-	0	13	3.31	-	22	-	53.5	-
	13	14.1	-	715.8	-	0.03	-	55.8	-	7.6	-	0	11	3.85	-	44	-	70.0	-
	12	14.2	-	726.0	-	0.05	-	65.0	-	11.3	-	4	60	3.62	-	34	-	68.0	-
	Mean	14.0	-	714.8	-	0.05	-	54.6	-	10.2	-	1	25	3.42	-	30	-	56.0	-
24	11	14.1	-	717.6	-	0.06	-	91.1	-	24.0	-	0	66	3.05	-	22	-	65.0	-
	10	14.0	-	713.3	-	0.03	-	56.0	-	3.8	-	0	11	3.31	-	34	-	50.0	-
	9	13.9	-	715.6	-	0.11	-	83.8	-	10.2	-	0	3	3.30	-	31	-	45.5	-
	8	13.5	-	713.3	-	0.05	-	48.4	-	21.6	-	0	11	3.79	-	33	-	74.0	-
	7	13.9	-	716.5	-	0.04	-	109.0	-	24.1	-	0	93	3.44	-	32	-	56.5	-
	6	14.4	-	732.4	-	0.02	-	85.6	-	28.5	-	0	97	3.86	-	48	-	66.0	-
	5	14.4	-	713.9	-	0.03	-	157.7	-	58.5	-	0	122	3.44	-	31	-	33.0	-
	4	13.9	-	715.1	-	0.04	-	67.3	-	39.4	-	0	29	3.42	-	25	-	52.5	-
	3	14.0	-	715.2	-	0.01	-	64.8	-	24.1	-	0	40	2.99	-	20	-	64.0	-
	2	13.8	-	722.6	-	0.01	-	181.0	-	84.2	-	0	162	2.61	-	12	-	41.0	-
	1	14.1	-	719.8	-	0.04	-	116.1	-	26.5	-	0	106	3.39	-	22	-	31.0	-
	Mean	14.0	-	717.7	-	0.04	-	96.4	-	31.4	-	0	67	3.33	-	28	-	52.6	-

Table 7.5. Changes in damage (insect...unplantable) of Rwandan beans stored for 16, 20 and 24 months (bag numbers 1-33) in the second underground experiment.
I - beginning of experiment (0 months); II - at opening of pit (either 16, 20 or 24 months).

		Storage Related Damage																											
		Insect (%)		Mold (%)		Rodent (%)		Germinated (%)		Total (%)		Broken (%)		Discolored (%)		Torn Pericarp (%)		Small (%)		Wrinkled (%)		Dented (%)		Inedible (%)		Unplantable (%)	
Months	Bag #	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
16	33	10.0	-	3.0	-	0.3	-	0.0	-	13.3	-	2.0	-	6.3	-	0.0	-	8.0	-	6.0	-	11.3	-	30.0	-	40.3	-
	32	7.0	-	2.0	-	0.0	-	0.0	-	9.0	-	1.7	-	8.0	-	0.7	-	7.0	-	5.7	-	7.7	-	21.7	-	29.7	-
	31	7.3	-	2.0	-	0.0	-	0.0	-	9.3	-	1.0	-	10.3	-	2.0	-	9.7	-	6.0	-	7.7	-	26.7	-	33.3	-
	30	9.3	-	1.0	-	0.3	-	0.3	-	10.9	-	2.3	-	6.3	-	1.3	-	7.7	-	6.3	-	6.3	-	27.3	-	34.3	-
	29	9.0	-	0.7	-	0.0	-	0.0	-	9.7	-	1.7	-	9.0	-	1.3	-	8.0	-	6.0	-	7.0	-	26.0	-	36.0	-
	28	9.3	-	2.3	-	0.3	-	0.0	-	11.9	-	0.7	-	7.0	-	1.7	-	9.0	-	5.3	-	4.7	-	28.7	-	33.7	-
	27	14.0	-	2.3	-	0.0	-	0.0	-	16.3	-	2.0	-	9.3	-	1.7	-	7.3	-	7.0	-	7.3	-	29.5	-	40.0	-
	26	11.0	-	3.0	-	0.0	-	0.0	-	14.0	-	1.0	-	5.7	-	1.7	-	10.7	-	5.0	-	8.0	-	22.3	-	32.0	-
	25	13.7	-	1.3	-	0.7	-	0.0	-	15.7	-	2.7	-	8.3	-	1.7	-	9.7	-	7.0	-	7.0	-	25.0	-	35.0	-
	24	10.0	-	3.0	-	0.0	-	0.0	-	13.0	-	0.3	-	7.0	-	4.0	-	11.7	-	5.0	-	7.3	-	29.3	-	43.0	-
	23	11.7	-	1.0	-	0.0	-	0.3	-	13.0	-	0.3	-	4.7	-	0.0	-	10.0	-	3.0	-	6.0	-	20.0	-	26.3	-
	Mean	10.2	-	2.0	-	0.1	-	0.1	-	12.4	-	1.4	-	7.4	-	1.5	-	9.0	-	5.7	-	7.3	-	26.0	-	34.9	-
20	22	10.7	-	2.0	-	0.0	-	0.0	-	12.7	-	2.0	-	6.7	-	1.7	-	6.7	-	7.3	-	6.3	-	26.7	-	33.7	-
	21	12.3	-	7.0	-	0.0	-	0.0	-	19.3	-	0.7	-	8.3	-	0.3	-	14.7	-	4.3	-	4.3	-	29.3	-	40.0	-
	20	12.7	-	2.0	-	0.0	-	0.0	-	14.7	-	1.3	-	0.0	-	2.0	-	8.0	-	4.3	-	6.3	-	19.0	-	29.3	-
	19	8.7	-	1.0	-	0.0	-	0.0	-	9.7	-	1.0	-	5.0	-	1.7	-	7.0	-	5.0	-	5.0	-	19.7	-	25.7	-
	18	9.7	-	0.7	-	0.3	-	0.0	-	10.7	-	1.3	-	6.7	-	1.3	-	7.7	-	5.0	-	4.7	-	16.3	-	29.0	-
	17	10.0	-	2.7	-	0.0	-	0.0	-	12.7	-	0.0	-	6.0	-	1.3	-	8.3	-	7.0	-	5.7	-	20.3	-	32.0	-
	16	6.3	-	2.0	-	0.0	-	0.0	-	8.3	-	1.7	-	6.0	-	2.3	-	5.3	-	4.3	-	3.3	-	18.7	-	22.7	-
	15	10.7	-	3.3	-	0.3	-	0.0	-	14.3	-	1.0	-	5.7	-	0.7	-	11.0	-	4.7	-	4.7	-	25.7	-	33.3	-
	14	8.3	-	1.7	-	0.0	-	0.3	-	10.3	-	1.0	-	6.0	-	2.0	-	6.7	-	5.0	-	5.3	-	20.3	-	27.0	-
	13	10.0	-	0.7	-	0.0	-	0.0	-	10.7	-	2.7	-	8.3	-	1.3	-	9.3	-	6.7	-	6.0	-	23.3	-	34.3	-
	12	7.0	-	3.0	-	0.3	-	0.0	-	10.3	-	0.3	-	9.3	-	0.0	-	11.3	-	5.0	-	5.0	-	22.7	-	36.0	-
	Mean	9.7	-	2.4	-	0.1	-	0.0	-	12.2	-	1.2	-	6.2	-	1.3	-	8.7	-	5.3	-	5.1	-	22.0	-	31.2	-
24	11	11.3	-	1.0	-	0.7	-	0.0	-	13.0	-	1.0	-	8.0	-	0.7	-	11.7	-	6.0	-	7.0	-	30.7	-	41.0	-
	10	12.0	-	3.0	-	1.0	-	0.0	-	16.0	-	1.7	-	7.0	-	0.0	-	8.0	-	4.7	-	5.3	-	26.0	-	34.0	-
	9	8.0	-	2.3	-	0.3	-	0.0	-	10.6	-	1.7	-	7.3	-	1.0	-	7.7	-	5.7	-	5.7	-	21.0	-	32.3	-
	8	10.0	-	2.0	-	0.0	-	0.3	-	12.3	-	0.3	-	7.7	-	1.0	-	5.3	-	7.3	-	8.3	-	28.0	-	34.0	-
	7	7.0	-	0.3	-	0.7	-	0.0	-	8.0	-	1.0	-	4.0	-	1.7	-	6.7	-	4.7	-	3.7	-	16.7	-	21.7	-
	6	15.0	-	0.0	-	0.3	-	0.0	-	15.3	-	2.0	-	7.7	-	1.7	-	9.3	-	6.7	-	9.3	-	30.0	-	40.3	-
	5	9.7	-	1.7	-	0.0	-	0.0	-	11.4	-	1.7	-	7.3	-	1.7	-	7.3	-	6.0	-	7.7	-	30.0	-	35.3	-
	4	24.0	-	4.0	-	1.0	-	1.7	-	30.7	-	2.0	-	9.0	-	1.0	-	5.0	-	5.0	-	0.0	-	31.7	-	40.7	-
	3	7.0	-	1.7	-	0.0	-	0.0	-	8.7	-	0.3	-	6.3	-	2.3	-	6.0	-	4.0	-	3.3	-	16.3	-	25.3	-
	2	7.0	-	1.7	-	0.7	-	0.3	-	9.7	-	2.7	-	6.0	-	1.3	-	8.0	-	4.0	-	4.3	-	21.7	-	29.3	-
	1	10.3	-	0.7	-	0.0	-	0.3	-	11.3	-	2.0	-	6.3	-	1.0	-	9.3	-	5.7	-	8.3	-	26.7	-	37.7	-
	Mean	11.0	-	1.7	-	0.4	-	0.2	-	13.4	-	1.5	-	7.0	-	1.2	-	7.7	-	5.4	-	5.7	-	25.3	-	34.3	-

Percent hard-to-cook and mean instrumental hardness increased from 0 to 4 and 4 to 8 months in a consistent and expected pattern (Table 7.2). Likewise germination decreased substantially with time (Table 7.2).

There were modest increases in insect damaged beans at 4 and 8 months (Table 7.3) indicating that insects were able to do some additional damage prior to being killed by the hermetic conditions. Significant increases in mold damaged beans (Table 7.3) were indicated at the 4 and 8 month samplings compared to the initial levels. However, the results did not suggest further increases during the 4 to 8 month period. Total storage related damage was high at 4 and 8 months as a result of the insect and mold damage (Table 7.3).

The percentage of discolored beans (Table 7.3) showed significant increases especially by the 8 month sampling. This damage category should be followed closely as this experiment continues. Little change was observed in either the inedible or the unplantable categories at 4 and 8 months.

The results obtained to date in this experiment show high levels of consistency in the data with several trends which should be carefully followed.

7.4. Summary and Conclusions

These tests have shown that underground storage can be successfully applied under the climatic and soil conditions of Rwanda. This type of storage with its controlled atmosphere seems to effectively halt insect attack. It may also slow down the irreversible color changes due to aging processes of beans, but this requires further tests for confirmation.

Certain problems remain to be resolved, and great caution should be exercised in extending this technology. It should be emphasized that this technique demands even more careful management and supervision than more conventional methods. A disadvantage is that sampling and even simple visual inspection, important grain monitoring tools, are impossible. Monitoring grain temperatures with thermocouples is feasible and could be used in large scale storage.

At this stage the applicability of underground storage is necessarily limited to long-term and relatively small-scale storage. The storage periods at the producer level are too short and grain removal too frequent to reap any benefits from underground storage. Many technical problems remain to be solved before underground storage can be applied to large-scale operations such as the cooperatives or OPROVIA/GRENARWA. The problems of how to properly seal larger storage units first have to be resolved.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. General

1. Management is the single most important aspect to improving storage at all levels. It includes:
    a. Assessing quality going into storage.
    b. Monitoring quality throughout storage.
    c. Taking corrective action where necessary.
2. Storage structures in most cases are adequate for good storage if properly managed. In some cases modifications can be made to ease monitoring and improve storage conditions.
3. A system of quality standards (formal or informal) which could aid in describing quality and provide incentives to improve quality would be a significant aid in improving storage management.
4. The long-term storage of beans requires low moisture contents and temperatures to maintain cookability which places additional demands on storage design and management.
5. Control of insects during storage is a major problem which requires the use of fumigants and insecticides under many conditions. Use of these materials should be carefully managed including application at proper rates and only when necessary. It is important that a variety of insecticidal materials (both natural and synthetic) be available for use to reduce the potential for development of resistant strains of insects. Applied research on the effectiveness of local insecticidal materials, insecticidal mixtures, rotation of insecticides, and new (back-up) materials is urgently needed.
6. Insect control failures can occur in any system for many reasons. Therefore, insect pests must always be closely monitored so timely corrective action may be taken.
7. The expertise of the FSM II research team in monitoring, sampling, laboratory analysis and diagnosis of problems should be utilized to improve storage management at the OPROVIA/GRENARWA, cooperative and producer levels. Efforts should also be made to extend this expertise to grain merchants.
8. Future work in the alternative management area should include increased activities in cleaning, handling and drying as well as continued work on storage problems.

9. Additional engineering expertise related to storage, cleaning, handling and drying is needed in Rwanda. A pool of well trained professionals is the key to the long-term success of improved storage management in Rwanda. Since the pool of Rwandans with the needed expertise is extremely small and educational programs are not available in Rwanda, a program to send promising students to other countries (preferably African) to obtain B.S. degrees in agricultural engineering or a related engineering field with emphasis on crop storage, handling and processing should be started immediately. In the short term, expatriate expertise is essential to insure that the existing program moves forward.

8.2. OPROVIA/GRENARWA Level

1. Obtaining uniform temperatures by aerating bag piles is difficult because of air distribution problems. Reducing heat load on the warehouse through the use of roof insulation and improving ventilation of the interior space, appear to be more effective means of reducing pile temperatures.

2. Reducing heat load and improving ventilation of interior space could be especially beneficial for long-term storage of beans since higher temperatures accelerate the development of the hard-to-cook problem.

3. Low moisture content (11-12%) is essential for beans going into long-term storage. Ambient air drying has potential to fill these drying needs. The experiments planned with the new drying bins should be carried out and evaluated.

4. Procedures to evaluate the quality of beans and sorghum as they are received with the option of segregating by levels of quality or of cleaning to improve quality should be implemented.

5. Improved facilities and equipment for cleaning, treating and handling are needed to upgrade service to customers and the quality of the product. The planning that has already occurred related to improved handling at the central warehouse in Kicukiro should be pursued and finalized.

6. A program should be initiated to regularly monitor stocks--including sampling, laboratory analysis, and written reports to upper-level personnel once a month--to promote improved storage management.

8.3. Cooperative Level

1. Aeration of well designed, well managed silos does not appear to be necessary or beneficial. The design of the silos provides good thermal protection of the storages. Therefore, temperatures were found to be uniform and low in unaerated compartments.

2. Relatively inexpensive modifications in silo structures can facilitate monitoring. Relatively simple equipment modifications can facilitate unloading the silos.

3. Problems were observed in storing grain in bulk in hangars since floor and wall areas do not appear to be designed with adequate moisture barriers. Storage in bags on pallets is recommended.

4. Regular monitoring based on procedures described in Appendix A should be implemented to improve storage management.

5. Poor management resulting from the rapid turnover and inadequate training of silo and hangar managers is a critical problem. Programs to train managers such as the recently initiated efforts involving the FSM II team, MIJEUCOOP and IWACU are essential.

8.4. Producer Level

1. All traditional storage containers tested can safely store beans (and presumably other grains) for at least a year if properly managed. Structures are not a major deficiency in the storage system. Management is of greater importance than the structures themselves.

2. Natural drying of beans and sorghum is generally effective in achieving sufficiently low grain moisture contents for safe storage with minimal damage due to molds. Efforts are not presently needed to develop artificial or improved natural drying methods. The possible exceptions are for beans harvested in January and sold to the government for long-term storage, and beans harvested in the lowlands during the rainy season. Traditional containers have the advantage of allowing continued natural drying of beans during storage.

3. The key management factor for all containers is the control of insect infestations. Effective contact insecticides exist and, when mixed with grain, can greatly minimize insect damage. Application is simple, inexpensive, and relatively safe for humans but should be selective. Further exploration of alternatives such as airtight storage is important.

4. Significant improvement in design of traditional baskets, the predominant storage container, is unlikely though means of rodent-proofing structures should be further explored.

5. Alternative storage containers, such as the metal and plastic drums under test, seem promising and should be further studied. They are more durable than baskets, rodent proof, and have the potential for controlling insects without insecticides. Though more costly, they may be economical when considered as a long-term investment.

6. Continued efforts to improve storage management at the producer level are justified to improve not only on-farm food supplies but also the quality of beans and grain entering market channels. This could have significant impact on storage at the cooperative, merchant and OPROVIA levels.

8.5. Underground Storage

1. Underground experiments were technically successful. However, special management is required to insure proper sealing of the plastic lining surrounding the beans and to insure that the lining is not torn during the process of covering with sand or earth. Failure to seal or tears in plastic could result in substantial loss without an easy way of monitoring problems as they develop.

2. Underground storage appears to be most applicable to longer-term storage because:

    a) it is inconvenient to remove stocks from an underground storage on a frequent basis, and

    b) if the underground storage is opened frequently the airtight (gas tight) environment, which is the primary advantage of this type of storage in Rwanda, is lost.

3. The airtight environment which creates the ability to control insects with no (or at least greatly reduced amounts of) insecticides during long-term storage is a major advantage of underground storage.

4. Another potential advantage, not yet confirmed, resulting from the airtight environment is the ability to maintain bright bean color (new crop appearance) during extended storage. If confirmed this could lead to economic benefit for marketing beans removed from the long-term storage. A series of experiments should be undertaken to answer

questions related to bean discoloration due to age in both airtight and non-airtight environments.

5. The level at which underground storage is applicable is a major question. The experiments that have been conducted involve storages of a size that could fit a cooperative or a group of producers. However, underground storage's primary technical application is to long-term (strategic) storage which is envisioned to be administered at the government or OPROVIA level.

6. Further work on practical management problems is needed before this technology should be considered on a major scale. This is particularly true if it is decided to pursue the use of larger size underground units for long-term storage.

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APPENDIX A

GRAIN QUALITY CONTROL PROGRAM
FOR
COOPERATIVE SILO MANAGERS

I. INTRODUCTION

Grain must be in good condition and of high quality to be stored without losses. Poor quality grain does not store well and is more likely to deteriorate during storage, thus causing financial loss to the cooperative. Furthermore, low quality grain often attracts fewer buyers, receives more complaints from buyers, or may even be sold at a lower price than a high quality product. Mixing poor quality with good quality grain decreases the overall quality and value of the product.

It cannot be assumed that grain stored for more than a few months will remain in good condition. One lot may encounter no problems without any control or intervention, while another lot of apparently similar quality may develop a problem and begin to deteriorate. Stored grain should therefore not be left unwatched and unattended. On the contrary, grain must be continually observed and monitored so that any problems which arise are detected early and resolved before major losses occur.

The key to successful storage is management, and an important part of proper management is quality control. A grain quality control program is designed to ensure that the cooperative purchases and sells high quality grain and that the quality of the grain is maintained with minimal losses during the storage period. The equipment and procedures recommended for controlling and maintaining quality are described below.

II. EQUIPMENT REQUIRED

1). One bin thermometer
2). One deep bin sampling cup (probe)
3). Four one-meter threaded metal rods plus T-handle for attaching to bin thermometer and sampling cup
4). One set of hand sieves for beans and sorghum with solid bottom pans
5). Several bowls or pans for holding grain samples
6). Two forceps for manipulating grain and insects
7). One hand magnifying lens (10 or 15 power)

III. PROCEDURE FOR INSPECTING GRAIN WHEN RECEIVED

Inspect each lot submitted for sale to determine its quality and suitability for storage and marketing by the cooperative. Quality should be assessed if possible in two steps: (1) make a quick visual inspection of the entire lot, and then (2) take a small sample (about 1 kg) of the lot. The rapid inspection is conducted when the grain brought by the producer is poured into a pile on the floor or into another sack. The aim is to identify and remove any large objects (rocks, bricks, sticks, etc.) prior to weighing and to determine whether the general quality of the lot is uniform or not. A distinct part of the lot may be of unacceptable quality, for instance, but could be removed from the rest instead of rejecting the entire lot.

A representative sample is then taken ensuring that grain is obtained from all parts of the lot; the sample is in fact a composite of many smaller sub-samples mixed together. This can be accomplished by inserting a bowl 8-10 times into the falling stream of grain as it is poured from one container to another, or by taking a handful or cupful of grain from 8-10 different locations in the pile of grain already poured on the floor.

The physical quality of the sample should be determined with respect to moisture content, foreign material, damaged grain, and insects. The following is an explanation of each of these quality factors, their significance for storage, and the methods used for their determination.

1). Moisture content (MC) is the amount of water contained in the grain, expressed as a percentage on a wet weight basis. Grain must be relatively dry to be stored properly and maintain its quality. High moisture grain will become moldy over time, and lose its commercial value and fitness for human consumption. In Rwanda, we consider 13% MC to be the maximum safe limit for storage of sorghum and for long-term storage of beans. An MC of 15% is satisfactory for shorter-term bean storage (less than 6 months).

Preferably MC should be measured with a moisture meter calibrated for the grain being tested and verified regularly for accuracy. If no meter is available, a tactile test using teeth or fingernails can, with practice, provide satisfactory results, i.e. determine a degree of hardness indicating that grain is sufficiently dry for safe storage.

2). Foreign material (FM) is all material other than sound undamaged seeds of the grain being purchased. This includes stones, dirt clods, dust, pieces of stems and panicles or pods, insects, rodent pellets, seeds of other crops or plants, and even broken pieces of the grain being purchased. For the most part, this material has no food or commercial value, and contributes to storage problems by promoting insect and mold development.

FM has two components: (1) fine material which can be determined by sieving (measure or estimate the amount which passes through an appropriate sieve), and (2) large material which can be assessed by hand picking through that part of the sample remaining on top of the sieve. The amount of FM is thus the sum of percentages by weight of these two components. In Rwanda, we consider that high quality grain contains less than 1% by weight of foreign material.

3). Damaged grain (DG) is the grain which has been severely injured by either insects, rodents, molds (fungi), sprouting, or abnormal maturation (small, shriveled grain). Grain damaged by any of these factors is considered by most Rwandans to be unfit for human consumption and for planting material. The amount of DG can be determined by hand-picking a small but representative sample of grain offered for sale. In Rwanda, we consider that high quality grain consists of less than 1% by weight of damaged grain.

4). Insects (IN) are a major cause of weight and quality loss in stored grain. If not controlled, insects can greatly increase in numbers over time with a resultant increase in grain loss. Besides the obvious damage (holes and tunnels) due to the feeding activities of insects, severe attacks may produce objectionable odors and even lead to mold damage. In such cases, nutritional quality and germinability of the grain can also be significantly reduced. The ultimate result is of course financial loss to the cooperative.

The principal insects causing loss to beans and sorghum in storage infest these crops in the field prior to harvest. Routine control measures, such as proper insecticidal treatments, must therefore be taken as grain is placed into storage. The extent of insect infestation can be determined by examining the fine material obtained from sieving and counting the number of insects found (both live and dead). In Rwanda, we consider 50 insects per kg of grain (equivalent to 5000 insects per 100-kg bag) to be a heavy infestation and grounds for refusing to purchase such grain.

IV. PROCEDURE FOR MONITORING GRAIN DURING STORAGE

1). Measure grain temperature in each compartment every two weeks using a bin thermometer inserted to various depths (bottom, middle, top) towards each of the corners as well as the center. Leave the thermometer at least four minutes at each location within the compartment, then remove to read the temperature and record on the appropriate form.

If the temperature has increased 2°C or less since the previous reading at the same location, no action is required. If the temperature has increased more than 2°C since the previous reading or there has been a gradual increase over several readings, then take a sample with the deep bin sampling cup at that location. In many cases, such a rise in temperature is the result of increased biological activity caused either by insects or molds. Therefore, the sample taken should be examined immediately as described in the next section (IV.2).

2). Take routine grain samples once a month from each compartment, regardless of temperature readings, using the deep bin sampling cup inserted to various depths (bottom, middle, top) towards each of the corners as well as the center. It is also advisable to take a sample through the unloading spout, as that area of some silos has proven to be a favorable location for insect development and infestation. A minimum of one sample (about 200 g) from each sampling location should be sieved and examined for the following:

(a) Off-odors (smell the sample to detect musty, fermenting, or rancid odors or those due to high insect populations)

(b) Presence of live insects (sieve the sample and pick out the insects from the fine material which passed through the sieve)

(c) Percent of insect and mold damaged seeds (pick out 100 seeds <u>at random</u> and count the number of these seeds with holes or rather obvious evidence of insect damage, as well as the number of seeds with visible mold on their surface).

Record all information obtained on the appropriate form.

V. ACTION

1). If there is evidence of an <u>insect</u> infestation in progress (visual observation of live insects), then a fumigation of the compartment or other appropriate insecticide treatment of the grain is required.

2). If there is evidence of <u>mold</u> growth or development (presence of an off-odor characteristic of fungi or increased levels of mold-damaged grain), this is the result of high grain moisture content. The following two options are then available:

(a) Remove grain from the compartment and sell or use immediately. However, moldy grain or portions of grain stocks which have high levels of mold should be destroyed (burned and/or buried) as they may be quite toxic to both humans and livestock.

(b) Remove grain from the compartment and spread in a thin layer to dry, either on the floor inside a building or outside in the sun on a tarp. In the latter case, precautions should be taken so that grain can be quickly covered and protected from rain. Stir and turn periodically until grain is sufficiently and uniformly dry. Confirm that the moisture content of the grain has returned to a safe level as described in section III.

It may be more practical and convenient to unload the compartment progressively and separate the grain according to quality (triage). Good quality grain could be placed in an empty compartment or temporarily in clean bags, while the poor quality or "problem" grain is spread out for drying as indicated above. If the grain in the top layer of the compartment is good, it can be unloaded through the top loading port and transferred easily to another compartment.

Once dried, the grain can be replaced in storage if the quality is acceptable. If the quality has already deteriorated, however, the best course of action may be to plan for its rapid sale. Remember though that moldy grain should be destroyed as explained above.

If the cause of the problem or the action required is unclear, or for any advice on the management of stored grain, contact the Grain Quality Laboratory of the GRENARWA II-Research Project at OPROVIA (B.P. 953, Kigali - tel: 2946, 2947, or 2948).

APPENDIX B

AIR-TIGHT METAL GRAIN STORAGE CONTAINER FOR RWANDAN FARMERS (EXPERIMENTAL)

PURPOSE:

To provide a durable container for Rwandan farmers for safely storing small quantities (100-200 kgs) of cereal and legume grains which will minimize losses and maintain grain quality for medium and even long-term storage. This container may also be suitable for the conservation of seedstocks by agricultural research organizations, seed agencies, rural development projects, communal/ cooperative groups, and others.

FEATURES:

*Durability
- Sturdy, heavy-duty construction
- Long-lasting (10-20 years)

*Insect control
- Allows safe and effective treatment of grain with insecticidal dusts (eg: Actellic)
- Allows safe and effective fumigation (eg: Phostoxin) because of gas-tightness
- May control storage insects without insecticides because of hermetic conditions (depletion of oxygen, build-up of carbon dioxide)

*Rodent proof

*Water-tight (moisture proof)

DIMENSIONS: height: 0.75 m
diameter: 0.50 m

VOLUME: 0.15 m^3

STORAGE CAPACITY: 110 kgs (approx.)

MATERIALS:

- 2 heavy-duty (3 mm thick) cylindrical metal spools available at TOLIRWA in Kigali at 500 FRW each. One is left intact and serves as the main portion of the container. The other is cut in order to open and flatten, and from this the two circular end pieces (bottom and top) of the container are cut.

- 1 heavy-duty plastic PVC pipe plug fitted with rubber gasket to permit air-tight closure. The plug is inserted into the container top towards the edge and used for filling and unloading the container. A plastic collar is heat glued onto the base of the plug, and the collar is then fastened with a dozen rivets to the container top.

A circular rubber strip is wedged between the collar and the container top in order to maintain the hermetic condition of the container. The first two prototypes contained plugs whose openings were 14 and 16 cm in diameter. Total costs to assemble the entire orifice range from 1500-2000 FRW.

- Anti-rust paint (interior and exterior)

WEIGHT: 40 kgs (empty)
150 kgs (filled with grain)

ESTIMATED COST: 4000-5000 FRW ($50-62 US)

ESTIMATED LONGEVITY UNDER NORMAL WEAR: 10-20 years

POSSIBLE IMPROVEMENTS:

- Capacity can be doubled to 220 kgs by welding a second spool to the first at minimal additional cost (1000 FRW for extra spool, paint, welding and labor)
- Handling and moving the container may be facilitated by welding simple metal handles on opposite sides of the container
- Optimum size of orifice at the top needs to be determined through tests and experience, but costs tend to rise exponentially with increasing diameter.

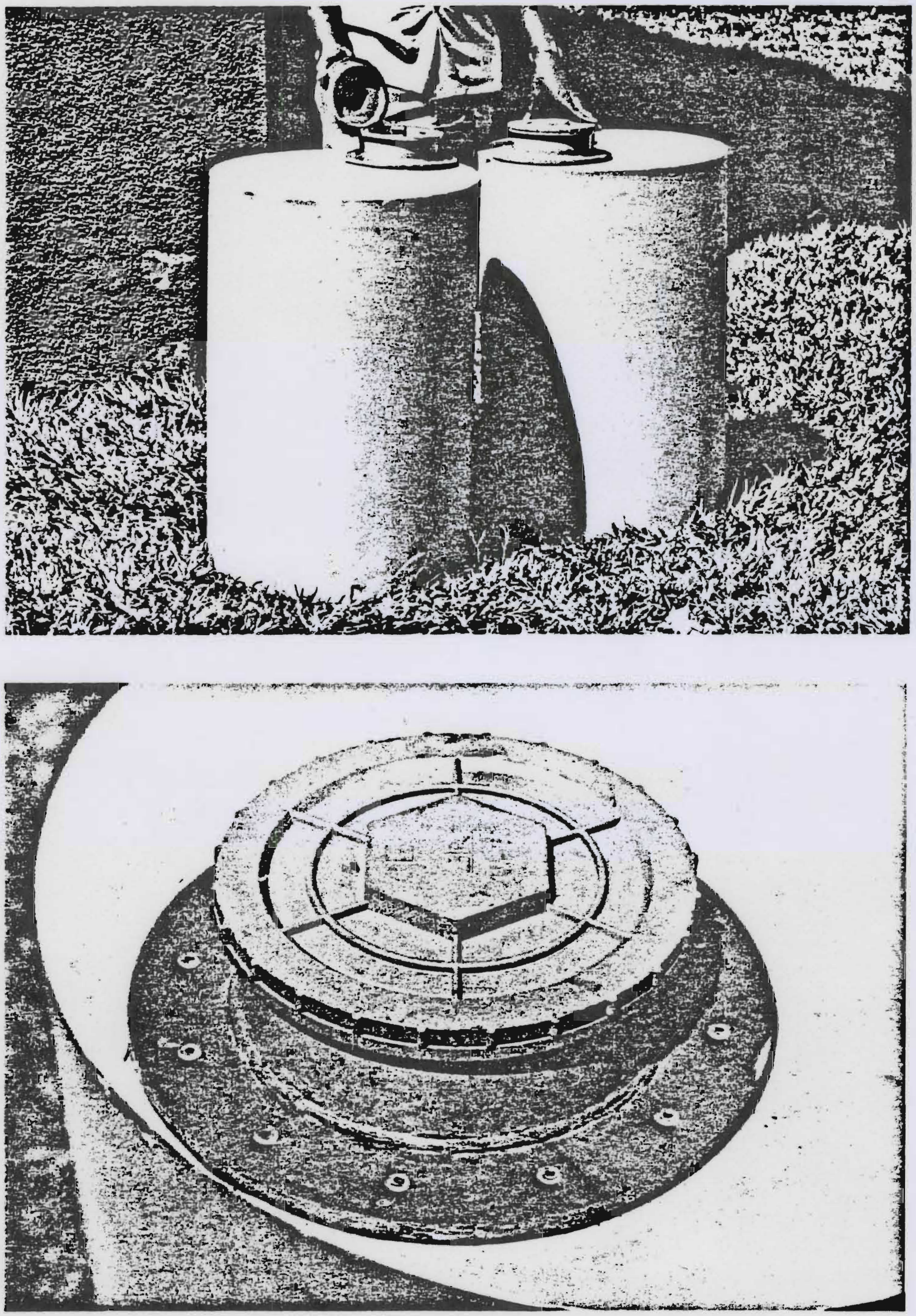

Figure B.1. Two views of experimental airtight metal container.