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A STUDY OF STORAGE CHARACTERISTICS OF MAIZE IN CONCRETE AND PLYWOOD BINS UNDER HOT HUMID CONDITIONS

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "A Study of Storage Characteristics of Maize in Concrete and Plywood Bins Under Hot Humid Conditions", submitted by Daniel Lantei Lamptey in partial fulfilment of the requirements for the degree of Master of Science.

J.B. McQuitty
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Date 12 March 1979

ABSTRACT

Serious deterioration of stored grain in the humid tropics has been and continues to be a source of considerable loss of valuable produce. The need for investigations aimed at minimizing these losses is very apparent.

The prime objective of this project was to investigate, using available local materials, effective, economical, and easily installed grain storage bins for the local small farmer in Ghana, cultivating 0.8 to 2.0 ha manually. Six bins, three of each of precast concrete pipes and of plywood, were used for the storage project. About 1.35 tonnes of maize (15.6%, wet basis) were stored in each bin. The bins were located in an environment that simulated Ghanaian temperature and humidity conditions for the months of July to December. In addition to ambient conditions, grain temperatures were monitored over a 24-week storage period at 24 locations within each bin, that is, at three depths or levels and eight positions per level. Grain moisture contents were determined before the grain was placed in storage. Moisture contents again were determined at the middle and end of the storage period. Microbial analyses also were carried out on the grain at the same various stages of the project.

Visual observations and analyses of variance of the data indicated that, at the end of the project, grain in the concrete bins was more damp than that in the plywood bins. The degree of mustiness and caking was higher in the concrete than in the plywood bins. Also, there was decay of grain in the vicinity of the walls of the concrete bins but not in the case of the plywood bins.

Temperature variations occurred at the various positions and levels within the plywood bins, especially during the first 12 weeks of the storage, but not in the concrete bins at any stage of the experiment. There was not much temperature variation within any of the bins after about 13 weeks of storage. After the grain had become warmer than the ambient, further heating was slow and temperature variations within the grain bulk were minimal. The overall grain bulk temperature was significantly warmer ($P < 0.01$) than that of the ambient.

The distribution of the major storage fungi, *Aspergillus sp*. and *Penicillium sp*. was independent of level (depth) or position (radial spacing) within the grain bulk. Germination capacity of the kernels was reduced from an initial figure of 45% to 0% by the end of the project.

There was no significant difference between plywood and concrete with respect to grain temperature. There was, however, a significant difference ($P < 0.01$) between plywood and concrete with respect to the redistribution of moisture within the grain bulk. Redistribution was more marked in the concrete than in the plywood bins. The apparent higher moisture permeability of plywood than that of the concrete used in this study appeared to prevent excessive moisture contents in the grain adjacent to the bin walls, with an accompanying decrease in the rate of grain deterioration.

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1. INTRODUCTION

1.1 Concept, Definition and Theory of Storage.

Safe storage must be provided for most agricultural produce until it is required for consumption. This is necessary because crop production is seasonal whereas consumption is continuous. Storage has been practised by mankind for a very long time. Biblical documents indicate that storage was used to maintain the supply of grain during the great famine that affected the ancient land of Egypt (Genesis: Chapters 42-50). This revelation from the Bible suggests that mankind probably has been trying to improve the quality of food storage for as long as the need for storage has been recognized.

Over the past century, agriculture in developed countries has been transformed from self-sufficient, labour-intensive farming to large-scale, energy-dependent enterprises. On the other hand, agricultural production in the developing countries is rising only slowly and increased food production cannot satisfy increasing food requirements. Losses in growing crops normally are recognized readily. Losses from disease, insects, rodents or nutrient deficiencies are reflected in lower yields at harvest time. However, losses in stored food are not observed so readily and the extent of deterioration in the quality of stored produce is seldom fully appreciated until too late.

The Food and Agriculture Organization (FAO) and other international agencies are now producing estimated figures on worldwide annual farm produce losses in storage. An FAO estimate of worldwide annual losses in storage indicates that 10 percent of all stored grain is lost, that is, 11.8 million tonnes of grain losses due to insects or

90.7 million tonnes due to failure to store properly (Wolpert, 1966). More food could be made available if post-harvest losses were prevented or minimized. Proper post-harvest handling and storage of a crop are essential components of a production system. The increase in grain crop yields obtained as a result of the introduction of high-yielding varieties, control of field pests, soil fertilization and the use of modern machinery to cultivate large areas of land may be of little value unless post-harvest losses can be minimized.

The object of storage or preservation is to take produce at its point of maximum palatability and nutritive value and keep it at this level instead of allowing it to undergo natural changes which render it unfit for human or animal consumption or for any other use. During storage, however, the original quality of the grain cannot be improved.

Most farm produce is stored before it is processed, marketed or consumed. In its simplest terms, storage may be just a mere holding of the produce per se until it is consumed or sold off the farm. At the other extreme, storage may involve complex handling operations and storage facilities in permanent structures. The period of storage may vary from a few hours to a year, or even more, depending on the produce and the storage facility in use.

2. THE TROPICAL ENVIRONMENT

2.1 Physical Characteristics.

Hot damp areas of the world normally are found in the tropics and sub-tropics. The tropical belt is that area which lies between the Tropic of Cancer (latitude 23.5 degrees North) and the Tropic of Capricorn (latitude 23.5 degrees South), and contains about one quarter of the land surface of the earth. It also holds about one third of the world's population. The sub-tropical belt lies on either side of the tropics within latitudes 40 degrees north and 40 degrees south.

In general, hot damp areas are characterized by fairly high temperatures usually in the range of 21°C to 35°C. Seasonal and diurnal temperature variations are small. Skies are usually overcast with considerable diffuse radiation intensity.

Rainfall is between 2000 mm and 3800 mm per annum. The rate of evaporation from free water surfaces is low. There is a bimodal rainfall pattern in certain areas in the lowland forest and coastal regions.

Humidities are high during the day and the drop in temperature at night may be accompanied by deposition of dew. Windspeeds are generally low except winds that immediately precede rainstorms.

In the tropics, one must distinguish between those regions which, although geographically in the tropics, have a climate that can be regarded as temperate and those areas that are truly tropical. The former are so regarded because of their altitude or other factors, whereas the latter are very warm and humid throughout most of the year.

In relation to post-harvest problems, five storage climatic conditions have been described. These are base [illegible] the four essential criteria affecting deterioration of the harvested crop. These are rainfall, humidity, temperature and harvesting date. Application of this information has been used to define a storage climatic pattern (SCP) for each area of a country. On the basis of an SCP, the types of problems and, therefore, the pattern of handling and type of storage likely to be the most successful, can be predicted. These SCP's for the humid tropics may be categorized (Hall, 1973) into the following:

1. Single rains and harvest during rains; storage conditions: 75-80% relative humidity for at least four months, otherwise below 75% and temperature below 23°C with a maximum of about 32°C. Drying and insect problems therefore prevail.
2. Double rains and harvests following two rain peaks with little natural drying after first crop; storage conditions: 70-75% relative humidity for at least four months and temperature ranges between 23-27°C with a minimum of about 16°C. Drying and insect problems with harvest I and insect problems only with harvest II.
3. Double rains and harvests following two rain peaks with increase in humidity during storage; storage conditions: 70-75% relative humidity for 10 months and temperature ranges 23-27°C with minimum of 16°C. Moisture absorption and insect problems therefore prevail.

2.2 Maize production, storage and utilization in ~~the~~ lowland tropics.

In the developed countries, corn or maize (*Zea mays*) is often described as "the poor man's cereal". This is because very little maize enters into the diet and does not serve as a whole meal or as a substitute for any of the recognized cereal staples such as wheat, barley or oats. In North America and Western Europe, where wheat is consumed on a very large scale, maize, if grown, serves mainly as feed for livestock and poultry and, to a lesser extent, as raw material for industrial products such as glucose, flour and starch. Some maize is utilized as a vegetable, or boiled or roasted on the cob.

Food grain production (million tonnes) in Africa is currently about 51 for cereals, eight for oilseeds, and four for pulses (Hall, 1977). The main cereals grown in West Africa are sorghum and pearl millet (6.4 million tonnes), maize (2.4 million tonnes), and rice (1.9 million tonnes) (Albrecht and Vallaeys, 1977). Sorghum and millet are most widespread and are well adapted to the Sudanian zone. Maize is much favoured in the humid areas, especially in the transition between the savannah and the forest zones. Annual per capita grain production in the humid regions is not very high (Nigeria, 67 kg; Ghana, 68 kg; Ivory Coast, 120 kg) (Albrecht and Vallaeys, 1977). Yields per unit area or per capita have increased little over the years and are very low in comparison with those known from research to be possible.

For maize, the yields vary according to country. Variation (Albrecht and Vallaeys, 1977) is from 1110 kg/ha (Nigeria) to 450 kg/ha (Togo). The maize production pattern in the lowland humid tropics varies from region to region and also from people to people (Table 2.1). This variation depends mainly on the rainfall regime. A typical farmer in a biomodal tropical rainfall SCP will have 1 to 2 ha under manual cultivation, predominantly for the production of maize. He may harvest up to 1000 kg/ha or up to 2000 kg/ha with local and improved cultivars

TABLE 2.1. MAIZE PRODUCTION IN THREE TROPICAL REGIONS (TREHARNE AND GREENLAND, 1977).

	Production (kg/ha x 10^6)				Yield (kg/ha)			
	1961-5	1972	1973	1974	1961-5	1972	1973	1974
Africa	9.09	12.82	11.06	1 .16	934	1065	942	1108
Latin America	27.00	35.18	37.57	38.06	1228	1384	1450	1892
Far East	11.29	13.72	15.16	14.74	1000	1071	1040	1046

Source: FAO Statistics. 1974.

Note: The actual increase in production during the last decade (Table 2.1) is attributed to greater land area rather than to increase in unit yield.

respectively (Hall, 1977).

Maize grown in the first rains matures in July and after being left in the field to dry for four to six weeks is harvested in August when rainfall is reduced. However, there is little sun at this time and relative humidity is still very high. This ambient condition at the time of harvest renders drying by sun and natural air a very lengthy process allowing for much pest and mould infestation.

All the produce is handled on the farm and stored for varying lengths of time. Some 85 percent or 52 million tonnes of Africa's foodgrains remain on the farm (Hall, 1977). Consequently, there is a very considerable emphasis being given to grain storage at the farm level

Traditionally, the farmer places his cobs, with or without sheaths, in a crib on the farm or in the village. From his store, small amounts are removed periodically and shelled by hand for consumption or sale. In some locations, only small quantities are harvested for immediate consumption. The cost of storage varies with the quantity and type of grain, period of storage, the type of handling facilities required, and, in towns, the value of the space. For the small farmer, a satisfactory structure can be constructed using locally available material that has been tested for that purpose. Anthonio (1971) discussed the economics of storage with particular reference to market prices. He concluded that rapid improvement in storage methods in Nigeria and other developing countries in Africa was difficult partly because individual production was too low to justify economic use of modern storage facilities at the farm level.

Bins or silos made of concrete, metal or butyl-rubber have been installed on state-owned farms, co-operative farms and on research farms in Ghana. Generally, produce for export is handled by specially established boards, corporations or government departments which design and finance storage facilities. Pest control measures usually are carried out to minimize losses. On the other hand, locally grown produce intended for local consumption deteriorates in the farmers' and traders' storages. Money seldom has been made available to study local storage problems and to demonstrate improved handling and storage methods.

Utilization of maize as human food is more common in the developing parts of the world, particularly in the tropics with its rapidly expanding population. In these areas, farm yields are so low and uncertain as to place a greater premium on grains as items of food rather than as feed for animals or as raw materials for industry.

In the recent past, West African countries, with the exception of Liberia, have been under foreign jurisdiction. In general, where the colonial administrators considered that the local people were not short of food, they endeavoured to develop crops for export. These were groundnuts and cotton in the savannah zones, and coffee, cocoa, oil-palm and rubber in the forest zones. These commercial crops have all been given considerable attention by researchers over the years because these crops have been the principal source of foreign exchange for many sub-Saharan countries.

Lately, in Africa and other developing areas in the tropics, there has been considerable effort given to problems of grain storage. These include studies to identify solutions by analysing technical data and to implement relevant solutions within the existing social and economic order (Hall, 1973).

2.3 Ghana: Maize situation in Perspective.

2.3.1 Why Maize?

Maize is the country's most important staple cereal. It may be categorized into a number of market classes on the basis of consumer and organoleptic requirements.

In terms of texture, maize in Ghana (Figure 2.1) may be classified into the hard, well dried and often more expensive grain called "kuku dabi", and the slightly cheaper variety called "kpokploku". Maize may be available in a white, red or yellow colour, small or large kernels, and local or imported varieties. Ghanaian consumer preferences naturally tend to favour the indigenous varieties, especially the hard, white and small grained "kuku dabi" (Clottey, 1971). Yellow maize, which includes the imported American variety and which is used extensively in poultry feed, is less favoured. The prime objection to yellow maize as a food item may stem from the colour since, by tradition, a creamy and not a yellow colour is preferred in maize dishes of all types. The demand for "kenkey", one of the main maize staples, is currently so great that any decline in maize supplies is sharply reflected in the size of the ball of "kenkey". Fresh maize may be boiled or roasted on the cob and serves as a food to many people in the country.

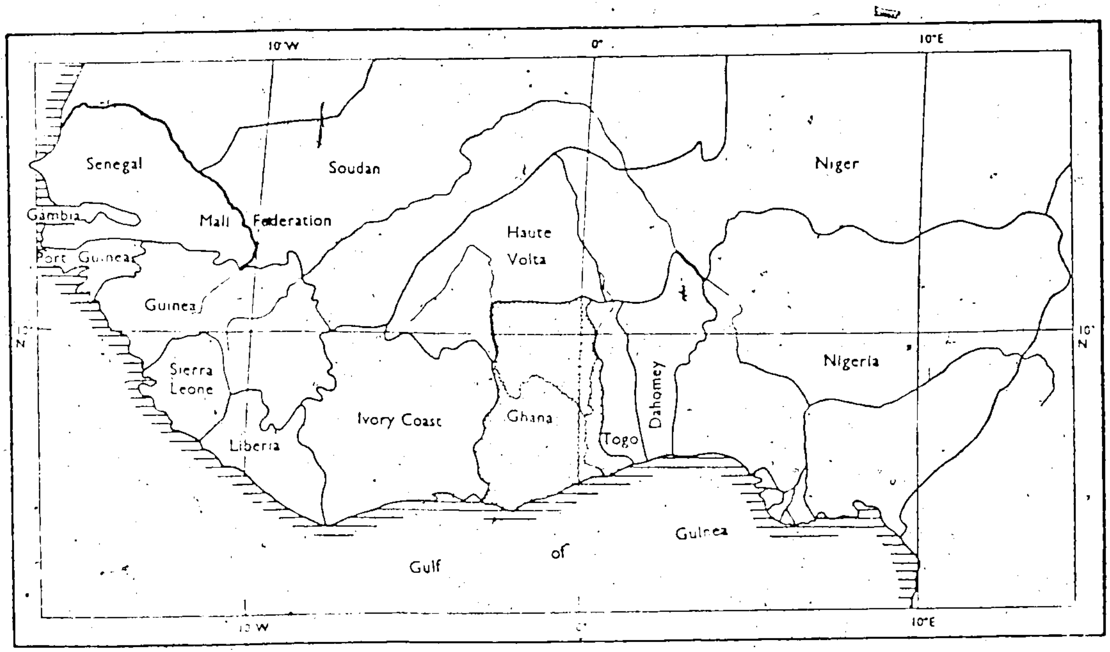


FIGURE 2.1: Ghana in its West African setting. (Beattie and Wills, 1962.)

2.3.2 Production, handling and storage of maize.

There are two crop seasons in Ghana. The major crop is planted in March and the minor crop in September. However, in the northern parts of the country (Figure 2.2) only one crop is grown. The maturity period varies from 80 to 140 days depending on the variety. Early maturing varieties are planted in the drier interior and coastal savannah areas. These are usually the yellow or white flint types. The longer-maturing varieties are grown in the forest and dry savannah zones. This may be related to the lengths of the wet seasons in those zones. The major maize growing areas are illustrated in Figure 2.3.

Quick-maturing varieties usually are considered to yield about 400-900 kg/ha (Nyanteng, 1972). Slow-maturing varieties may yield up to double these values. Yields up to 2840 kg/ha from improved varieties grown on agricultural experimental stations have been recorded

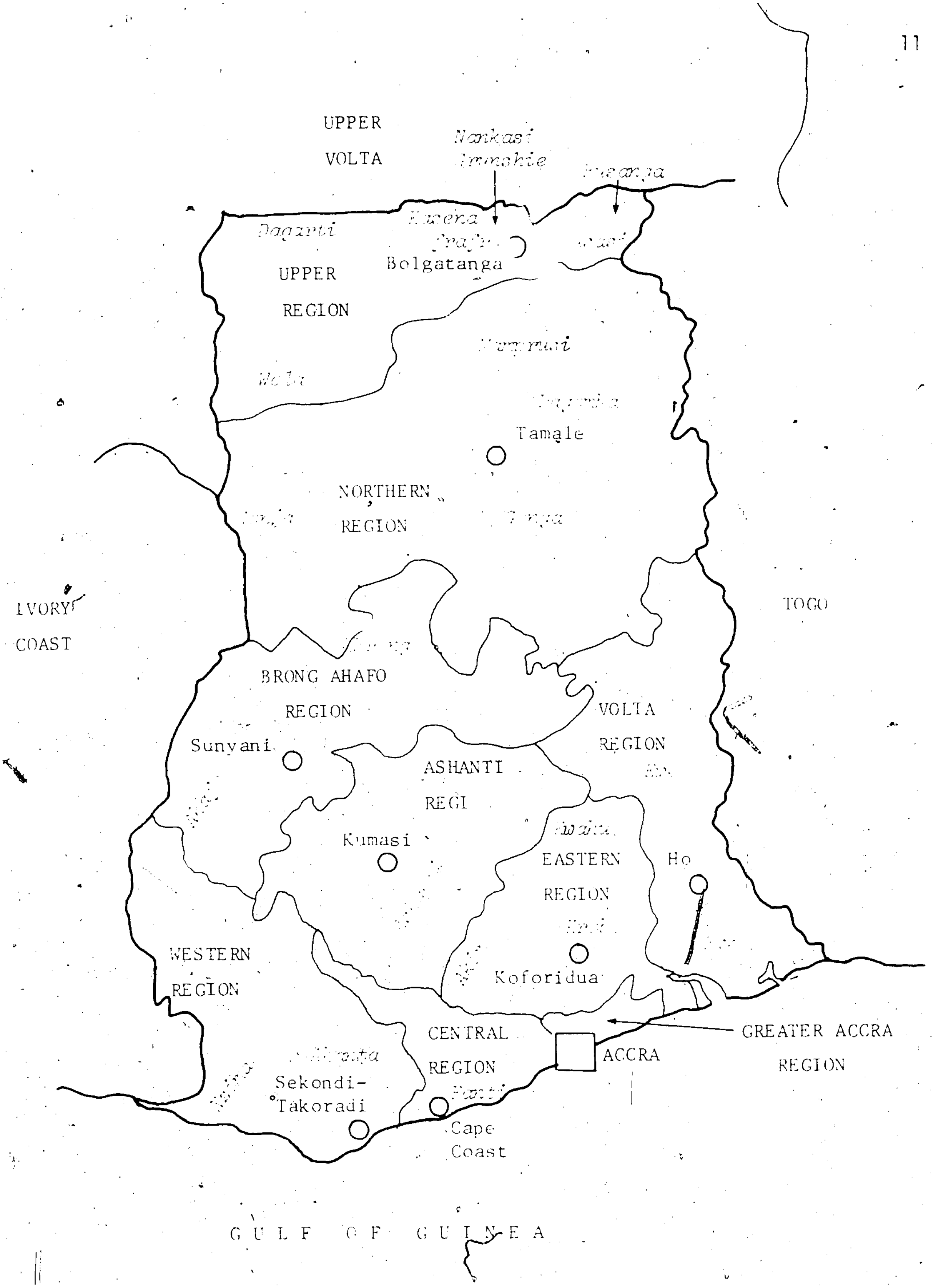


FIGURE 2.2: The nine Administrative Regions of Ghana showing some of the major ethnic groups.

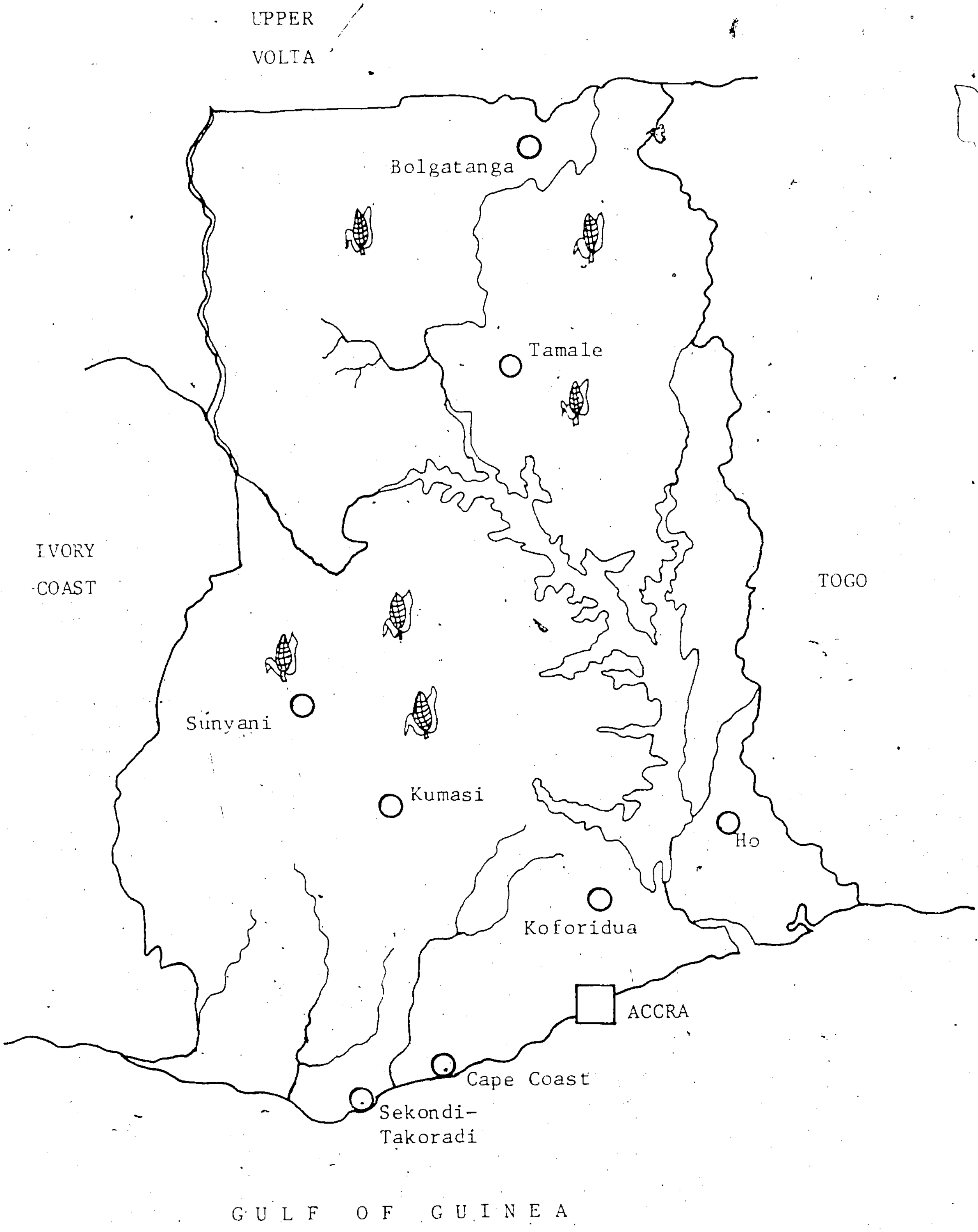


FIGURE 2.3: The major maize growing areas in Ghana.

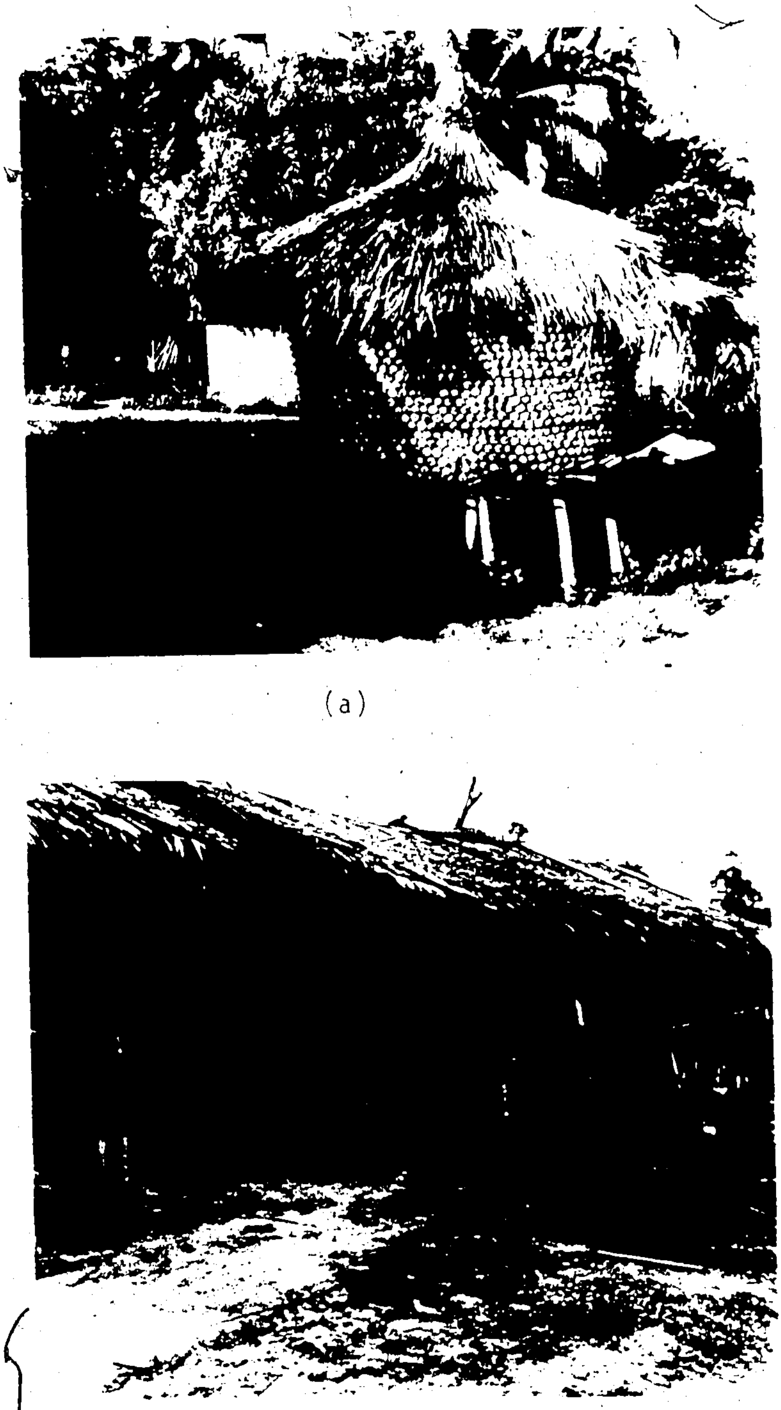
(Nyanteng, 1972). Grain production figures are shown in Table 2.2.

TABLE 2.2. FIGURES OF GRAIN PRODUCTION IN GHANA (from Crop Production Records, Ministry of Agriculture, Economics and Planning Division, June, 1977).

Year	Production (1000 tonne)
1970	481.51
1971	465.25
1972	402.27
1973	426.65
1974	485.57
1975	343.35

Traditionally, drying is achieved by the sun and natural air. There are various types of storage structures and traditional storage methods that are peculiar to the indigenous people and the regions. In the southern part of the Volta Region (Figure 2.2) and in other parts of southern Ghana, crib or barn storage is very common. The Ewe crib (Figure 2.4a) is an outdoor type and consists of a circular platform of radiating bamboo poles or timber raised about 1.0 m from the ground on bamboo or wooden staves. On the platform is built a compact circular stack of unsheathed maize cobs. The peripheral cobs are packed carefully to form a circular wall. The diameter increases as the stack goes up. The inner cobs are packed loosely. The stacks are usually about 1.8 m in both diameter (at the top) and height and covered with thatch, metal sheets or plastic materials.

The Ashanti barns (Figure 2.4b) are somewhat different. They



(a)

(b)

FIGURE 2.4: The Ewe crib (a) and the Ashanti barn (b). Note the aluminium sheet around the supports to prevent rodents from climbing up into the barn.

are made usually of oil-palm fronds, split bamboo and sometimes of roughly sawn timber. They are built about 1.0 m off the ground and have walls 1.5 m to 2 m high. They are roofed with thatch or shingles. These may take between 4.5 to 8.5 m^3 of maize on the cob, complete with sheath.

In the northern part of the country, maize is stored in a similar way to guinea corn and millet. Storage is in granaries which vary in shape and size according to tribe and area. The people of the north-west, the Dargarti and Lobi, (Figure 2.2) build their granaries as part of the compound houses. The granaries are usually 1.8 m in both diameter and height, with conical-shaped roofs ending in a manhole which is the only entrance. The people in the north-east, that is, the Grunshie, Kasena and Nankansi, build their granaries separate from the compound house. These granaries are taller and may have a "skirt" of "zanna" of plaited grass (Figure 2.5a) protecting the walls from rains. The people in the central part of the northern region build their granaries of a "zanna" wall backed by wood (Figure 2.5b). These granaries are raised on wooden staves about 0.3 m high. In the southern areas of the country, unsheathed maize on the cob is hung in batches in fire places or kitchens, and also in trees in the compound.

Small 18-tonne silos for use by village maize storage cooperative societies were introduced into Ghana in 1955 (Forsyth, 1957). Circular resin-bonded plywood silos of similar capacity have been used for storage by cooperative societies at Adidwan and Sekodumasi, both in the Ashanti region (Forsyth, 1962). Concrete block and aluminium silos also have been in experimental use (Forsyth, 1962) at Adidwan and Sekodumasi. There are, however, no experimental results available to

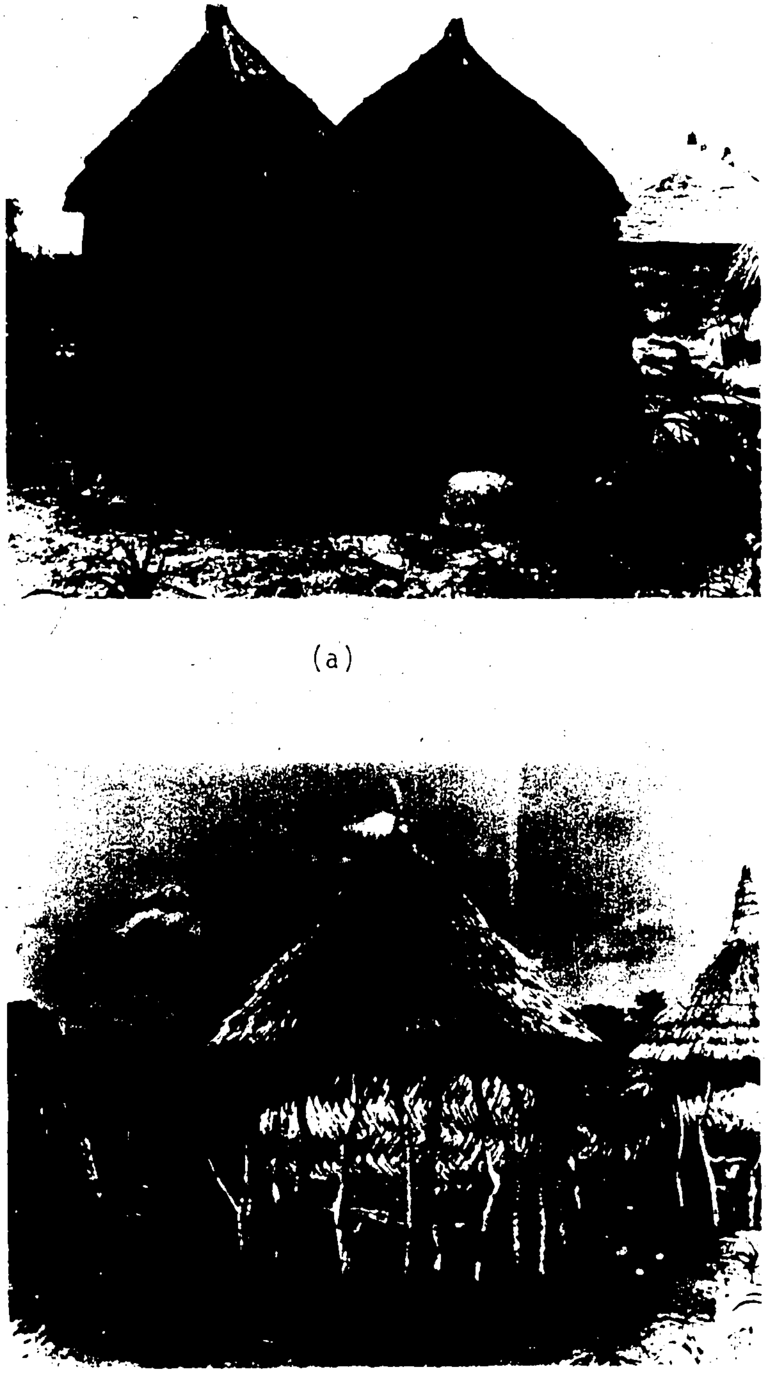


FIGURE 2.5: Granaries of the people in the Northern part of Ghana.
(a) Two Crunshie granaries showing "zanna" skirt around the granary in the background.
(b) Dagomba type of granary.

assess the storage characteristics of these silos. Forsyth (1962) indicated that the cooperatives had been able to obtain a premium price for their maize over that obtained for maize stored by traditional methods.

With the establishment of the Grain Development Board, several modern storage structures have been put up in many maize growing and consuming or distributing areas. Lately the butyl-rubber silo has been introduced and still is undergoing tests in the hot humid environment. The original black-coloured butyl-rubber used in these silos proved unsatisfactory, due to cracking resulting from solar radiation effects. These silos now have been replaced by white-coloured butyl-rubber and presently are being evaluated as to their durability (Vas, 1976).

2.3.3 The Problem Defined.

The main storage problem in humid Ghana is associated with the relatively high moisture content of the grain at harvest time. Moisture content (wet basis) can vary between 20 and 30 percent. Traditional maize drying as described previously is, therefore, a very lengthy process allowing for much pest and mould infestation before the grains go into storage. Even then the moisture content is often too high for safe storage.

Harvesting and processing of grains normally precede the heavy tropical rains. Almost every year, these rains wash out bridges between the growing and the consuming centres. The feeder roads, therefore, frequently are rendered impassable to motor traffic, with the result that many farms may be inaccessible. Hence, food remains on the site of production and must be preserved there until more favourable conditions prevail for transporting the produce to the consuming areas.

Most tropical areas have suffered acute maize shortages at one time or another. While in some areas these shortages have been the result of rain failure, in other areas the cause has been improper storage systems (Nyanteng, 1972). Ghana, for example, experienced an acute maize shortage in the early part of the year 1969. This led to the importation of about 2500 tonnes of yellow corn under the World Food Aid Programme to alleviate the situation. Controversy over the price per bag of the donated maize led to its boycott. The commodity remained unsold and the maize supply situation continued to deteriorate (Nyanteng, 1972).

In 1976, there was a severe mould infestation problem in most of the silos installed in the country. This necessitated the emptying of all the affected silos by the Food Distribution Corporation. Later in that year there was another maize shortage in the country. The maize situation gradually worsened and a bag of about 90 kg sold for ¢300.00* (about $260.00) as against the Government's control price of ¢17.00 ($15.00) (Vas, 1976). As an emergency solution, the Government imported maize and rice as a supplement to ease the situation.

A factor which tends to affect the progress being made in improving structures for storage is the unit used in the sale of maize on the local markets. This is on a volume basis, that is, price is a function of volume and not weight. Weevils bore holes into the kernels and reduce weight but the overall volume is not affected. This does not impose any financial burden on the producer, the middleman or the

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* The Cedi (¢) is the local currency. At that time the official exchange rate per a Canadian dollar was ¢1.15.

seller. Hence, there is no incentive to control the factors that cause weight reduction. Consequently, during the "lean season" or period of scarcity, the consumer might pay a higher price for an inferior product compared to that paid subsequent to harvest.

Recent research in many developing countries has been geared towards modifying existing traditional structures and methods of storage. Most of these traditional structures and methods had been used to hold only a few kilograms of produce for short periods.

In some cases unwanted parts of the maize cob are stored as well as the kernels. The Ewe crib, for example, stores maize on the cob complete with sheath. In this way, only about one-third of the storage space is used by the actual grain kernels. Space, therefore, is being paid for to store the unwanted cobs and sheaths. As a result, a farmer may require about three times the storage space he would otherwise require for in-bin storage. However, a typical farmer until recently had the services of his whole family on the farm to help construct and maintain these cribs.

This situation has changed rapidly due to the steady increase in urbanization in Ghana, coupled with compulsory, free education policies. Fewer hands are available on the farms nowadays and the extra free labour enjoyed by the local farmer is no longer available. Continued use of these structures and methods is no longer convenient for the average farmer and does not fit into the present socio-economic environment.

Research, therefore, must be focussed on the use of local materials which can meet the requirements of modern storage practices. Any proposed storage unit has to be tested under the particular conditions of temperature, humidity, grain type, microflora and microfauna prevailing. Storage system improvements must start at the farm level. Recommended units, apart from fulfilling their expected structural functions, should be easily transportable, relatively cheap and easy to install by the typical farmer. Before the widespread use of more complex and expensive storage facilities are considered for a particular country or area, the following conditions may have to be met:

1. An effective farm level storage must be appropriate to local conditions with respect to climate and management skills.
2. The creation of more effective village cooperative societies for the production of maize.
3. A comprehensive and detailed study should be undertaken to quantify the extent of losses and contamination of grain under farm storage conditions.
4. Techniques or developments relating to improved storage must be backed up by effective extension programmes.
5. A pricing system based on grain quality.
6. A ~~guaranteed~~ guaranteed price for the farmer to encourage farmers to adopt improved storage facilities and techniques.

2.3.4 Project Objectives.

The main objectives of this project were:

1. to utilize for the construction of on-farm grain storage bins in Ghana, a material or materials that would be readily available locally at an acceptable cost,
2. to investigate the portability and ease of installation of the bin on the farm,

3. to investigate the degree to which the selected material or materials can withstand adverse environmental conditions during the storage of cereal grain,
4. to study the temperature, moisture and microbial distributions in the grain bulk during bin storage under hot, humid conditions.

3. LITERATURE REVIEW

A grain bulk has been recognized as a man-made ecological system (Sinha, 1973), a system in which living organisms and their non-living environment interact with each other. Deterioration results from the interactions of the biotic and the abiotic factors. These may include physical factors such as temperature, humidity, geographical location and granary structure; chemical factors such as oxygen supply; biological agencies such as bacteria, fungi, insects, mites, birds, rodents; and man with his methods of handling, storing, transporting and disinfecting products (Figure 3.1).

By affecting grain and its quality, these variables do not as a whole act alone or all at once. Initially, the deterioration rate is slow but as an optimum balance is achieved between the variables and a prolonged storage period, deterioration is speeded up and the loss in grain quality increases.

3.1 Temperature.

When grain is placed in a storage bin, it is subjected to any temperature changes taking place in the outside atmosphere. The surface responds quickly to ambient temperature variations but the centre of the grain mass is least affected by these variations (Hall, 1957). In general, temperature changes occurring within a grain mass are due to both internal and external sources of heat. The main internal sources of heat are the heat of respiration from microbes and insects, and field heat. External sources of heat are due to the diurnal temperature fluctuations and seasonal changes in temperature which are influenced by

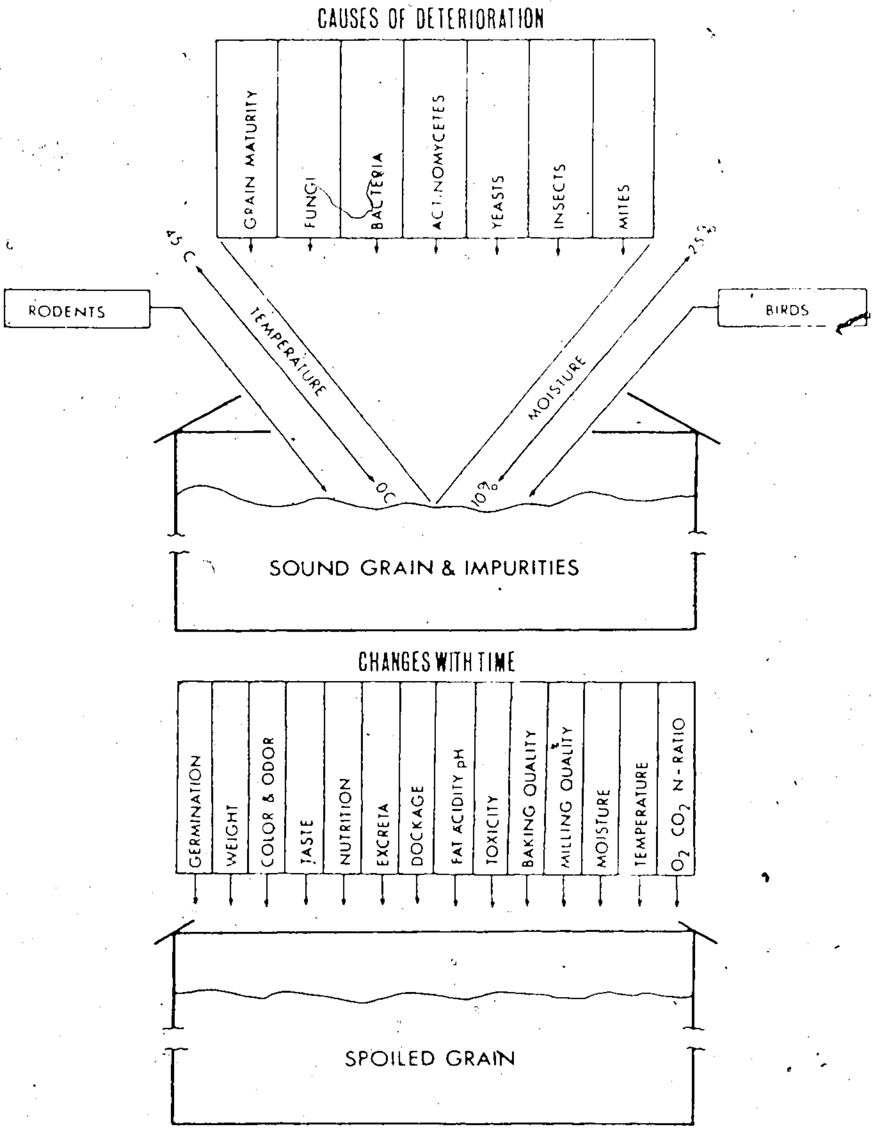

FIGURE 3.1: A diagramatic representation of interrelations among the grain bulk, organisms, and their abiotic environment in the spoilage of stored grain. (Sinha, 1973).

geographical location. For example, winter temperatures of stored grain are up to 18°C higher in Texas than in North Dakota (Muir, 1973). Also small grain bins, painted white or completely shaded, store grain in better condition than large unpainted or unshaded bins (Muir, 1973).

Initial temperatures of stored grain are established by the temperature of the harvested grain, that is, field heat. The temperature, for example, of freshly harvested wheat and barley averaged 30°C when the atmospheric temperature averaged 23°C on a sunny afternoon in England (Williamson, 1964). This indicates that initial temperatures of freshly harvested grain in storage can be equal to or considerably higher than the atmospheric air temperature. If this high temperature of the grain is not reduced when the grain is put into storage, such high temperatures coupled with high moisture content encourage rapid deterioration of the stored grain.

Although changes in diurnal temperature affect grain temperatures in bins only up to 15 cm from the bin wall (Converse et al, 1969; Kelly, 1941; Muir, 1970), solar radiation causes the temperature of the bin wall to rise considerably above atmospheric air temperatures (Kelly, 1941; Muir & Wallace, 1971). On a sunny afternoon in Manitoba when the atmospheric air temperature was 28°C, the temperatures of the inside south wall in contact with wheat were 56°C in a black butyl-rubber bin, 39°C in a plywood bin painted red, and 37°C in a galvanized steel bin (Muir & Wallace, 1971).

Heat from external sources penetrates slowly into the grain bulk. Diurnal temperature fluctuations rarely affect the grain below a few centimetres from the surface (Sinha, 1973). At about 300 cm depth, the effects of the summer and winter temperature cycles are minimal and, if at all noticeable, are delayed by 2-3 months (Sinha, 1973). Smith (1969) calculated that, at a 10 cm depth, a daily difference of 10°C is reduced to 1°C and at 4 m an annual mean range of 40°C will be limited to 1°C. He concluded that it would take six months for the summer maximum atmospheric temperature to reach the 2.5 m depth.

Ampratwum (1969) indicated that, for a 1.22 m diameter metal bin, wheat at the 50.8 cm radial position cooled and warmed significantly faster than the wheat at the 30.48 and 10.16 radial positions, while wheat at the 30.48 cm radial position cooled and warmed significantly faster than that at the 10.16 cm radial position. He concluded that temperature differentials established were affected significantly by time, height from bin-base, spacing from vertical axis and moisture content.

Muir et al (1977a) reported from work on three types of farm granaries that, in mid-winter, the centre temperature of a plywood bin of diameter 2.9 m and a butyl-rubber bin of diameter 4 m were about 4°C and 10°C respectively, warmer than a cooled bin. During summer, the centre temperatures of all the three bins rose above the ambient air temperature. They indicated further that even though skirts were attached to the plywood bins to reduce air circulation under the bins, the bottom temperatures in the plywood bins were 9°C below those in the butyl-rubber bin which sat directly on the ground.

Temperature of the grain in a small plywood bin (2.9 m diameter and 2.4 m high) followed the ambient air temperature with about 2 to 3 months time lag (Muir et al, 1977b). Williamson (1964) had earlier indicated that there is a general tendency for the temperature of bulk stored grain to fall with atmospheric temperature but with a lag of 1.5

to 3 months.

The metabolic heat produced exclusively by dry grain has been calculated to be in the order of about 1 x 10^{-7} cal sec^{-1} cm^{-3}, and by damp grain to be approximately 1.3 x 10^{-5} cal sec^{-1} cm^{-3} (Oxley, 1948a). Physical characteristics such as thermal conductivity and diffusivity depend on grain moisture content and temperature (Table 3.1). Oxley (1948a) calculated the thermal conductivity of grains at different moisture contents and found it to be in the order of 0.0004 cal cm^{-1} sec^{-1} c^{-1}. The thermal diffusivities of grain are usually in the order of 0.00115 cm^2 sec^{-1} (Smith, 1969). The rather low thermal conductivity and diffusivity values of grain indicate that grain is a poor conductor of heat.

Heat will be transmitted from one grain particle to another by conduction only when they are in physical contact, and by radiation across the intergranular air. There also may be mass movement of this intergranular air, transferring heat more quickly by convection. The movement of heat in grain bulk, however, is initiated by temperature gradients in the bulk.

The low thermal conductivity of bulk grain is often an important contributing factor in causing a high rise in temperature from minor heat sources created by microorganisms and insects in the micro-environments within grain bulks. The temperature differences are less in small bins because heat has a rather shorter flow path from the centre to the walls in a small bin than in a large bin (Muir, 1973).

"Spontaneous heating" has been observed in stored grain. This may occur independent of any external cause (Zeleny, 1954). The heating is a direct result of the respiratory activity of the grain bulk itself

TABLE 3.1. THERMAL PROPERTIES OF MAIZE (Summarized from ASAE Data: ASAE D243.2, Agricultural Engineers Yearbook, 1977).

Grain or grain product	Moisture content percent, wet basis	Temperature range, deg C	Mean temperature, deg C	Specific heat Cal per gm deg C	Conductivity Cal per sec cm deg C	Diffusivity, sq. cm per sec
Corn, yellow dent	0.9	12.0 to 28.8	20.5 for	0.366	0.000336	0.000255
Corn, yellow dent	5.1	for sp. heat	sp. heat	0.404	0.000350	0.000246
Corn, yellow dent	9.8	8.7 to 23.0	13.8 for	0.438	0.000363	0.000233
		for diffusivity	diffusivity			
Corn, yellow dent	13.2	26.7 to 31.0	-	-	0.000422	
Corn, yellow dent	14.7	12.0 to 28.8	20.5 for	0.484	0.000380	0.000227
Corn, yellow dent	20.1	for sp. heat	sp. heat	0.531	0.000391	0.000217
Corn, yellow dent	24.7	8.7 to 23.0	13.8 for	0.567	0.000406	0.000222
Corn, yellow dent	30.2	for diffusivity	diffusivity	0.588	0.000412	0.000231

and the other biotic factors which are present in the grain bulk. The heating usually commences in localized areas of high moisture content and results in the development of hot spots.

Wallace and Sinha (1962) found that "hot spots" in stored Canadian wheat and oats could develop anywhere in a storage bin. Temperatures of up to 53°C in winter were obtained, usually highest at the base of the bulk of the grain. The heating of the grain was accompanied by killing off of the field fungi (Alternaria) and loss of germinability of the grain. A further study (Sinha and Wallace, 1965) showed that heating of the grain to a maximum of 64°C was initiated by Penicillium species. They noted interestingly that a hot spot does not infect an entire grain bulk even though the grain immediately affected is rendered unpalatable.

The heat may be generated more rapidly than it is dissipated by thermal conduction through the grain, by radiation, conduction and convection in the intergranular air, and by the evaporation of water. Consequently, the temperature of the grain rises. This rise in grain temperature increases the rate of respiration so that a continually self-accelerating process takes place. Deterioration from bin heating will occur if the temperature of the grain exceeds about 43°C (Zeleny, 1954). The respiratory activity of dry, insect-free grain is so low that the small amount of heat produced is normally dissipated without a significant increase in temperature. If the moisture content of the grain is sufficiently high to permit fungal growth, the fungal respiratory activity and the resultant heat production may be so high that increases in temperature occur. High temperatures in grain, if they occur, are a positive indication of spoilage.

Interrelations among several thermophysical properties of the grain and grain bulks, such as thermal capacity, temperature conductivity (thermal diffusivity), and "thermal moisture conductivity", and physical variables such as convection, conduction, radiation, evaporation, condensation, and absorption, are responsible for the transfer and exchange of heat and moisture through bulk grain. A careful measurement of temperature of the grain bulks of different sizes and stored in different types of structures is important for proper storage (Prevett, 1959).

3.2 Moisture.

All grains contain moisture which is present in two main forms: adsorbed water and water of composition. The amount of "free water" present is critical to the rate of deterioration of produce (Hall, 1970). Grains and their products, being colloids, are hygroscopic. They can sorb moisture from, or give it up to, the surrounding atmosphere until they are in equilibrium with it. Grain has its own characteristic balance (or equilibrium) between the moisture it contains and the water vapour in the air with which it is in contact. The relative humidity of an atmosphere in equilibrium with a product increases with the moisture content of the product until saturation of the atmosphere is reached. This equilibrium point is known as the equilibrium relative humidity (ERH). The moisture content of the grain when it is in equilibrium with the surrounding atmosphere is termed the equilibrium moisture content (EMC) (Hall, 1957).

For a good storage condition, the moisture content of food grains should be known at the time they are put into storage. Since moisture above a particular level is necessary for the development of microorganisms, deterioration due to fungi and bacteria can be prevented or minimized if grain with a moisture content in equilibrium with less than 60 percent relative humidity (for most species at tropical temperatures) is placed in storage. In general, the critical moisture content for maize storage has been estimated to be 12.5 to 13.5 percent (Christensen, 1973).

Various workers have noted relationships between grain moisture content and the relative humidity of the air with which the grain is in contact. Brockington et al (1949) concluded that the critical moisture content for the safe storage of maize in equilibrium with a relative humidity of 75% was 13.8 ± 0.2% by the Brown-Duval method and 14.7 ± 0.1% by the two-stage vacuum oven method. Milner and Geddes (1945), Gilman and Semeniuk (1948) had earlier found 75% to be the safe relative humidity. Christensen (1973) reduced the relative humidity limit to 65%. In general, above 65 to 70 percent relative humidity fungi develop and produce heat which results in an increase in temperature. The temperature so produced may reach 63°C, giving rise to what is termed "damp grain heating" (Sinha and Wallace, 1965).

At relative humidities below 70 percent, insect infestation may develop and an increase in temperature resulting from the respiratory activities of the insects may occur. The temperatures may reach 42°C, creating what is known as "dry grain heating" (Sinha, 1961).

The EMC and ERH of shelled maize have been studied by Tuite and Foster (1963). Their studies showed that the ability to absorb water progressively decreased with increased drying temperatures and the effect seemed to be permanent. Increase in ERH with increased temperature was inversely proportional to the decrease in EMC. This conclusion confirms the observation by warehousemen that there is greater difficulty in storage of artificially dried corn in that blue mould is common (Martin and Gilman, 1976).

A change in the temperature of a product affects the vapour pressure exerted by the moisture in the product, that is, its moisture content. The moisture content changes so that the humidity of the product atmosphere remains an almost constant fraction of that of a saturated atmosphere at the same temperature. Experimental results have shown that for wheat, if the moisture content remained constant in the 10 to 20 percent range, the ERH increased or decreased approximately three percent for every 10°C rise or fall in temperature (Aryest, 1965 ; Pixton and Warburton, 1971). Conversely, if the relative humidity remained constant, the moisture content of wheat decreased approximately 0.6 to 0.7 percent per 10°C rise in temperature (Oxley, 1948b). The relationship between temperature, relative humidity and grain moisture content is shown in Figure 3.2.

When grain is in storage, redistribution of moisture occurs. This phenomenon called "moisture migration" has been observed by Carter and Farrar (1943). Temperature gradients within grain bulk cause air density differences. The air density differences may establish a pressure gradient or pressure drop which leads to constant motion of the intergranular air by convection currents within the stored grain. As air moves from a warm to a cooler region, it is cooled. Its relative humidity rises and may reach saturation point when excess water will be deposited on the surface of the cooler grain (Joffe, 1958). The interchange of moisture usually takes place in the vapour phase (Anderson et al, 1943; Oxley, 1948b). It may also be a liquid flow across kernel contact points (Hart and Neustadt, 1957). Vapour diffusion occurs whenever the partial pressure of water is not uniform (Stewart, 1973). Stewart (1973) has summarized the three possible mechanisms of moisture migration in grain bulks. These are:

a) vapour diffusion through the air spaces
b) moisture diffusion through the kernel solid matter, and
c) moisture carried by convective air currents.

He concluded that of the above three mechanisms convection provides the primary mechanism for moisture movement in the large scale storage of grain.

Moisture migration results in localized increases of moisture contents (moisture pockets) which produce optimal conditions for fungal growth (Figure 3.3). The rate at which moisture migration proceeds is dependent on the size of the bin or silo. It is slower in small bins than in large bins. This is so because at most times of the year differences in temperature between the walls and the centre of the bins will be less in small bins than in large ones. There is a shorter heat flow path from centre to wall of a small bin than in a large bin (Muir, 1973).

The effect of temperature differences on the moisture contents of grain in different points of a bin has been studied by various workers. Anderson et al (1943) found that a temperature difference of 35°C across 1.83 m of grain with an initial moisture content of 14.6 percent caused the moisture content of the grain in the cold region (0°C) to increase to 20 percent in 316 days. Pixton and Griffiths (1971) had theoretically found that after 12 months at a constant temperature of 22.5°C and at a constant relative humidity, no

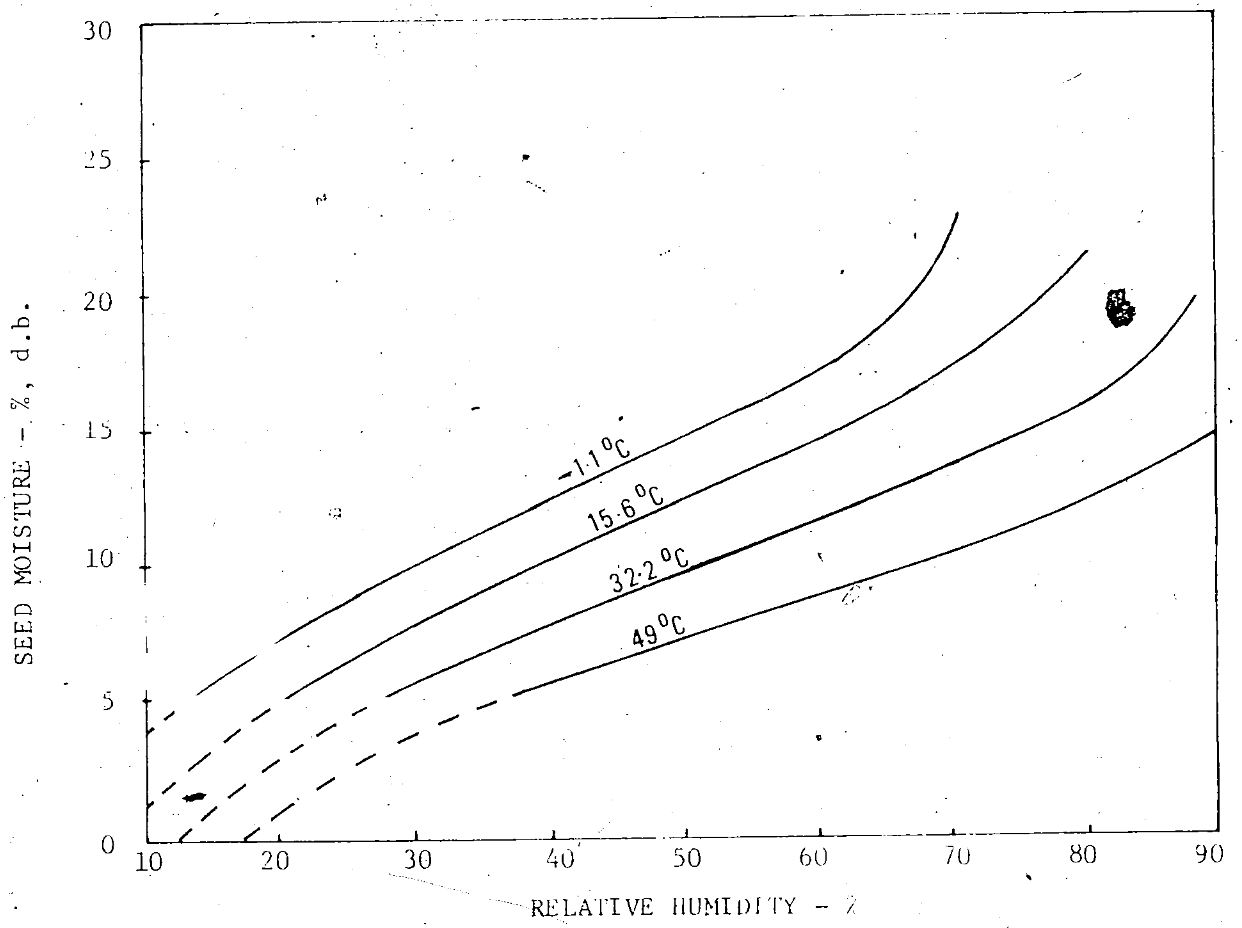

FIGURE 3.2: Effect of temperature on equilibrium moisture content of corn (maize). (Re-drawn with change of scale after ASAE D245.2, Agricultural Engineers Yearbook, 1977, page 396).

change in moisture content would have taken place in grain 50 cm below the surface of a large bulk. Ampratwum and McQuitty (1970) concluded from experimental work on wheat stored in circular steel bins of 1.22 m diameter and 1.52 m high, that moisture migration tended to be towards the upper layers where the top surface of the grain was open to the environment. Moisture variation among the radial spacings, and therefore the moisture variation in the horizontal direction, was not significant (Ampratwum and McQuitty, 1970).

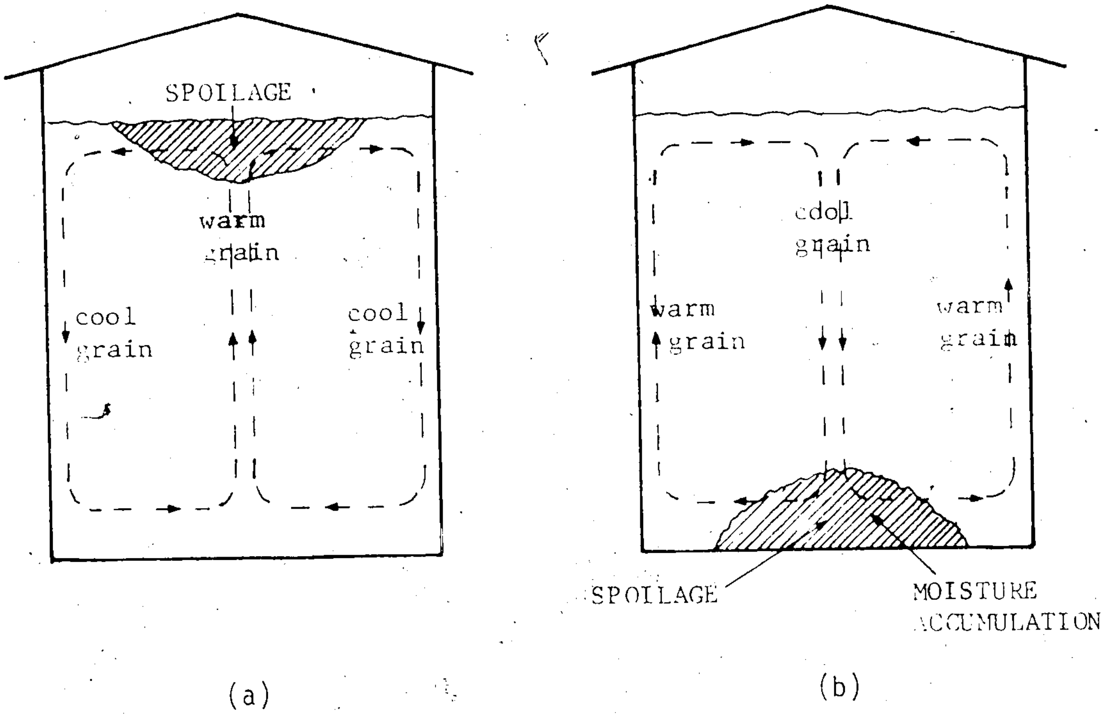

FIGURE 3.3: Convection air currents within a grain bin:
(a) warm grain in bin with colder ambient air
(b) cool grain in bin with warmer ambient air.
(Re-drawn after Brooker et al, 1974).

Redistribution of moisture in bins has been studied recently by Muir et al (1977a). In a 3-year storage experiment on tough and heavily-infested wheat, they indicated that an initial high moisture pocket at the top centre of a control plywood bin dried from 21.6 to 19 percent in 6 months and then down to 12.4 percent after 11 months of storage. The moisture content at the centre of the control bin decreased from 16.2 to 14.7 percent over 36 months of storage. However, wheat in a butyl-rubber bin increased in moisture content during the storage period. The increase occured at the surface and at 30- and 60-cm depths (Muir et al, 1977a).

Condensation problems, especially in metal silos, occur in the tropics, particularly in areas where the sky is clear during both day and night (Hall, 1970). Apart from changing the physical and engineering properties of grain and its products, moisture affects considerably the rates of growth and development of all the biotic factors as well as the rate at which chemical and physical changes take place. If grain is uniformly dry when put into storage and is kept dry and at constant temperature, damage due to moisture will be minimal.

In general, the development of moulds, bacteria and mites, and, to a lesser extent, of insects, can be prevented by reducing the moisture content of the grain to a level at which they will not readily grow. Drying grain to a moisture content of about 14 percent will limit the development of moulds, bacteria and mites but, for insects, the low moisture level required to restrict growth (8-10 percent) is uneconomic to attain, and maintain, in practice (Hyde, 1965).

3.3 Biotic Factors: Nature and Importance in Stored Grain.

The number of groups of living organisms that cause deterioration of grain in storage has been recognized by various researchers working on grain storage. These biological organisms include insects, fungi, bacteria, mites, rodents and birds. The extent and rate at which each of these agents affect grain depend on the type of microorganism involved, temperature and grain moisture content.

3.3.1 Insects:

Insect infestation of stored grain results in a weight loss. Insects bore holes into grain kernels and reduce the overall weight of the kernels. Contamination of grain by insects and their fragments and excreta reduces grain quality. Deterioration in stored grain also may result from insect respiration. This respiration in localized areas of the storage atmosphere is a possible cause of temperature gradients inside the grain bulk.

For post-harvest losses caused by insects, reliable estimates on a country basis are difficult to obtain. This is because of the variety of storage methods used, the continually-changing quantities in store, and the trading practices adopted. For example, the rate or degree of insect damage in bag storage may differ from the rate of damage in crib-stored maize. Subsistence farmers do not keep relevant records, but data collected from actual sample farms (Hall, 1969) show that in some specific situations losses exceed 30 percent (Tables 3.2 and 3.3).

Various experiments have been carried out to test for or determine the correlation between percentages of insect damage and weight loss. In Malawi, 3000 bags of maize infested with insects after two years in storage showed an apparent weight loss of seven percent (CCTA, 1958). Similarly, Prevett (1959) obtained a 25 percent apparent weight loss in parboiled paddy during one year in Sierra Leone, or an actual loss of about 41 percent due to infestation. In Ghana (FAO, 1969), cob maize stored in the sheath by farmers suffered losses from 8

TABLE 3.2. DATA RECORDED FOR WEIGHT LOSSES TO PRODUCTS DURING STORAGE IN A NUMBER OF COUNTRIES (Summarized from Hall, 1970, Table 4, Page 20).

Country	Commodity	Loss		Level of Storage	Period of Storage (months)	Cause
		(%)	10^6 tonne			
Ghana	Legumes	9.3	0.006	FTC	12	I
Upper Volta	Legumes	50 - 100		FTC	12	I
Nigeria	Legumes	10		T	6	I
Somalia	Grain	20 - 50		FTC	12	RI
Tanzania	Legumes	50		FTC	12	I
India	Food Grains	5.0	2.8	F	12	
Japan	Rice	5		FTC	12	I
U.S.A.	Maize	0.5	5.9		12	I
Thailand	Paddy Maize }	10		F		I

F - Farmer storage; T - trader storage; C - central storage depots; R - rodents; I - insects;

TABLE 3.3: EXTENT OF LOSSES OF PRODUCE DUE TO INSECT PESTS AT DIFFERENT LEVELS OF STORAGE (NON-EXPERIMENTAL) IN AFRICA. (Summarized and rearranged from Hall, 1970, Table 5, Page 21.)

Country	Commodity	Apparent Loss (%)		Level of Storage	Storage period (months)	Major Pest
		Damaged grains/kernels	Weigh loss			
Ghana	Maize		20+	F	8	Weevils
Benin	Maize	30 - 50		F	5	Weevils
Zambia	Maize	90 - 100		F	12	Weevils and Moths
Togo	Maize	20		T	6	Beetles
Uganda	Maize		5 - 10	T	6	Beetles
Rhodesia	Maize		12 - 19	C	24	Weevils and Moths
Uganda	Maize	35 - 38	10	C	9	

Note: F - farmer storage; T - trader storage; C - central storage depots percent to 16 percent over storage periods of 8-23 weeks, while cob maize stored without the sheath suffered a loss of 26 percent after 23 weeks. Shelled maize stored for a similar period showed a loss in weight of 34 percent. The average loss of crib-stored maize in a study in Kenya was 9.6 percent of the weight in four months. This figure rose to 23.1 percent in 6 months (Kockum, 1958). In another experiment in Uganda, Davies (1959) calculated that, in maize stored in a bamboo crib, a 10 percent bored sample represented a weight loss of 2.4 kg out of 91 kg or 2.7 percent. He also noted that the percentage of bored grain in crib-stored maize (untreated) in Uganda varies, very often from 45 to 75 percent.

Under reasonably good storage conditions in the tropics, infestations yielding 80 to 100 live weevils per 500 gm of produce after only six months in storage have been recorded (Hall, 1970). Generally insect development is accelerated by increase in temperature up to about 42°C. Hall (1970) indicated that if the temperature throughout a kernel, that is, inside each maize grain, can be raised to 66°C and maintained for four minutes (or 60°C for 10 minutes or 49°C for 20 minutes) all insect stages will be killed. Insects will not develop readily if the temperature is below 17°C (Hyde, 1965).

3.3.2 Microorganisms

Fungi are a major cause of spoilage in stored grains and seeds, and probably rank second only to insects as a cause of deterioration and loss in all kinds of stored products throughout the world (Christensen and Kaufmann, 1974).

As grain moisture content increases, water becomes available for use by parasitic microorganisms such as moulds. If the microbes are not controlled, they can multiply rapidly, create heat and cause deterioration of the grain (Hyde, 1965; Stewart & Britton, 1973). The variety of microorganisms which are present in spoiling grain depends primarily on moisture content and temperature. Various fungi have optimal temperatures for growth, usually in the range of 10 to 35°C. Fungal growth rate is low at low moisture contents and temperatures, and practically stops at a relative humidity less than 70 percent and temperature below 0°C (Brooker et al, 1974). The optimal temperature for growth of most grain moulds is between 25 and 30°C. Some moulds develop best around 37°C (Brooker et al, 1974). The minimum air relative humidity for mould spore germination can be as low as 62% for some moulds and as high as 93 percent for others (Frazier, 1967).

Intensive mould growth occurred at 12 to 15°C and between 40 and 60 days in tough grain with 14.5 to 17 percent moisture content, and between 20 and 30 days in grain with 18 and 19 percent moisture content (Sinha, 1973). Sinha (1973) again indicated that at 20 to 22°C, intensive mould growth occurs between 30 and 40 days in tough grain and between 7 and 10 days in damp grain. Grain does not spoil due to mould growth at any of these temperatures when stored for 60 days with 15 percent moisture content. The relationship between storage temperature, grain moisture content, insect heating, fall in germination and damp grain (fungal) heating is illustrated in Figure 3.4.

The most predominant microorganisms are several species of Penicillium and Aspergillus, also commonly referred to as storage fungi (Christensen and Kaufmann, 1969). Wallace and Sinha (1962) found that some unidentified species of Penicillium were the most common fungi in hot spots. Apart from visible seed discolouration, heating and mustiness, fungi in stored grain may produce unnoticeable mycotoxins (toxic fungi metabolites) which are fatal to man and animals. Serious human poisoning caused by moulds have occurred in many parts of the world (Scott, 1973).

Aflatoxins produced by a few strains of the storage fungus Aspergillus (especially A. flavus) are potentially the most hazardous to human health. Mycotoxicoses primarily involving the liver or kidney of both human beings and animals have been reported widely. High rates of liver cancer in southern Africa, Nigeria and Uganda have been confirmed by Doll (1969). Usage of spoiled grain has been thought to

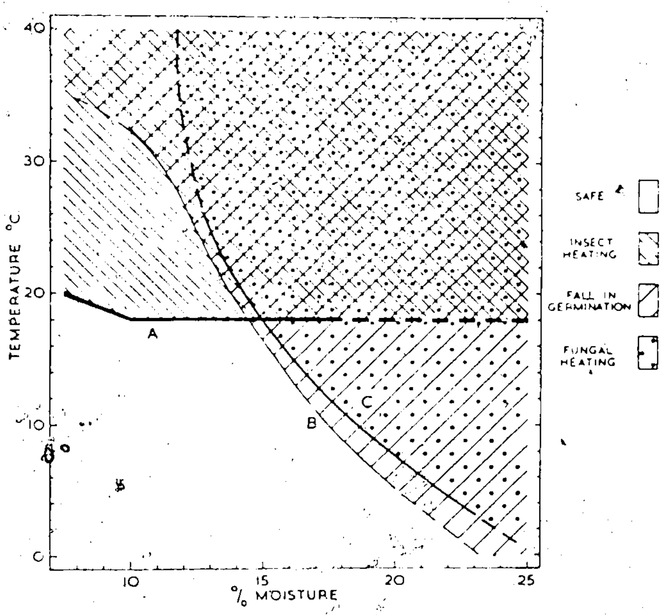

FIGURE 3.4: Relation of storage temperature and grain moisture content to insect heating, fall in germination (to 95% in 35 weeks storage) and damp grain (fungal) heating (After Hyde, 1965).

cause this ailment. A study in Uganda has revealed that temperature and relative humidity appeared to take precedance over rainfall in the rapid formation of aflatoxins in foodstuffs (Martin and Gilman, 1976).

One interesting discovery has been the demonstration of the nce of zearalenone* in samples of malted sorghum, in 27 pooled samples of 'sour' fermented porridge and beer made from maize and sorghum, and in two samples of mouldy maize off the cob from Swaziland (Martin and Gilman, 1976). This study has been extended to Lesotho (Martin and Gilman, 1976) where small quantities of zearalenone (up to 50 ppb) have been found in 16 of the 71 beer samples examined. The possible ingestion of zearalenone by most of the African population perhaps could explain the high incidence of certain diseases such as cervical cancer (Martin and Gilman, 1976).

The estrogenic syndrome in swine caused by Fusarium species is one of the best understood mycotoxicoses (Scott, 1973). Poultry are affected as well. The death of over 100,000 turkey poults in England in 1970 were traced to aflatoxins present in Brazilian groundnut meal in their feeds (Scott, 1973).

The accumulation of grain beetles in areas where grain has been spoiled by fungi has been studied by various researchers. Apparently some property of spoiled grain stimulated the downward movement of these insects. The response by Cryptolestes ferrugineus

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* Zearalenone (F-2): This mycotoxin has been observed generally in corn, and occasionally in barley. The fungi involved are various species of Fusarium. Zearalenone produces an estrogenic syndrome in swine consuming infected corn, characterized by swollen vulva in females, shrunken testes in young males, and enlarged mammary glands in both sexes. In females, it interrupts oestreus and may cause abortion in pregnant sows. Other animals affected by zearalenone are mice, guinea pigs, rats, cattle, chickens and turkeys (Hesseltine, 1976).

probably is induced by olfactory stimuli from one or more volatile compounds in the fungi or by-products of the fungi (Dolinski and Loschiavo, 1973). Surtees (1965) had attributed the underlying mechanism to a klinokinetic response to humidity. Watters (1969) observed that more rusty grain beetles emigrated from mouldy than from sound wheat and suggested that the main cause was a high CO_2 level associated with respiring insects and fungi. Dolinski and Loschiavo (1973) suggested that insect distribution in a grain bulk may be influenced by the presence of certain fungi in moist pockets of grain.

In addition to fungi that infect grain in storage (storage fungi), there are those that infect the grain before the grain is placed in storage. This group of fungi is known as "field fungi". Hyde (1950) found a significantly inverse correlation between the quantity of field fungi and the environmental temperature. It might be expected that fungal growth would be increased by high temperature, but as these were often associated with low humidities, retardation occurred instead. As primary invaders, field fungi will not readily reinvade seeds once they have been dried and remoistened, or when they have been invaded by other fungi. Moisture contents of 22 to 25% on a wet weight basis or of 28 to 33% on a dry weight basis, have been cited by Christensen (1965) and Christensen and Kaufmann (1965) as the lower limit for growth and development of field fungi.

3.3.3 Rodents, mites and birds.

Although insects are regarded as the main agents of loss, rodents also can cause significant losses of stored foodstuffs and contamination by excreta. Majumder (1968) cited 130 human diseases as being transmitted by rats, and noted that the Indian rat population was at least 2400 million. Each rat consumes about 26 g of food per day (Deoras, 1967) and contaminates a further 200 g; the daily human intake of cereals is about the same as the quantity which a single rat in a day renders unfit for consumption. Loss of produce due to rodents after harvest is, generally, less than that before harvest (Hall, 1977).

A number of mites associated with stored foodgrains are important economic pests. Under suitable temperate conditions and usually in materials with a relatively high moisture content, they multiply rapidly and can cause serious damage or loss (Hall, 1970). The presence of mites in a product is an indication that it is too moist for prolonged storage. Apart from causing damage to materials, mites are capable of effecting some degree of control on other pests in stored material. Many are predacious upon stored product insects, and upon the eggs and young stages of certain insect pests. Mites also feed on moulds (Hall, 1970).

Birds peck holes in bags and the amount of produce eaten, plus that which pours out of the bag (particularly with small grains such as sorghum and millet), can result in a loss of some 70 percent of the original weight of the bag (Hall, 1970). Birds also eat and cause loss in yield before it is harvested.

3.4 Other factors.

Methods of processing to which food grains are subjected prior to storage are known to affect their storability. During the processes of harvesting, threshing, shelling, steeping, cleaning and milling, damage to grain cells usually occurs. Mechanical harvesters produce cracks in grains and provide easy entry points for fungal spores and insects (Breese, 1964). Combine harvesters leave no time for grain to dry out between harvesting and threshing. These also cut green weeds with the grain and, during storage, moisture is transferred from the weeds and immature seeds to the drier, full grain kernels (Hall, 1970). Swathing, however, eliminates this problem in the temperate areas.

Conveying of produce from one place to another may affect the quality of the produce. Conveyors for bulk or bags, especially bulk, result in varying degrees of dropping and breakage of the grains. Separation and reconcentration of dust take place during conveying of the grain (Hall, 1970). Joffe (1963) reported that turning maize 13 times over a period of eight and a half months kept grain relatively cool and in sound condition. This operation, he added, substantially reduced the number of insects present in the turned grain. Adults as well as preadult stages of insects within the maize grains were killed by mechanical or physical disturbance (Joffe and Clarke, 1963).

Since the unbroken seed coat is the best protection for the grain from attack by microbes and insects, the role of this variable on seed health and microbial growth has been given attention by various workers (Wallace, 1952; Thompson and Foster, 1963). These studies showed that the lower the moisture content of the grain as it is handled, dried and transported, the more prone the grain will be to mechanical damage. With maize, the percentage of breakage sharply increases when it is dried below 12 percent (Thompson and Foster, 1963 Mechanical threshing also has been known to cause damage in grain kernels. Vas (1969) indicated that the mechanical parameters causing significant variations in percentage mechanical damage to wheat (with average moisture content of 10.4% w.b. and average grain-to-straw ratio of 1.00/1.71) are cylinder speed, concave clearance and feed rate. He concluded that increasing cylinder speed from 800 rpm to 1200 rpm increased mean damage from 2.9% to 12.4%. An increase in concave clearance from 6.35 mm to 19.05 mm caused damage to decrease from 7.7% to 5.4%. Vas (1969) went on to show that an increase in feed rate from 45.4 to 136.2 kg/min. resulted in decreasing damage from 7.1% to 6.0%.

Time of harvesting is an important factor with respect to maturity of the crop and also with respect to climatic conditions. In countries where the crop matures and must be harvested during the rainy season, major problems of drying must be solved. In most countries in the tropics and subtropics, crops can be infested prior to harvesting by insects. Investigations in countries such as India, Kenya, Nigeria and in the West Indies have revealed that many crops, including maize, beans and paddy, carry significant infestations of insects from the field into storage (Hall, 1970).

The effect of drying-air temperature on grain is critical. The temperature of the air must be kept below some maximum value depending on the intended use of the grain. A maximum grain temperature of 43°C usually is recommended for drying grain for seed (52°C will kill the germ in most grains); for milling, temperatures above 60°C should be avoided; and for feed grains, 88°C is often considered as the high temperature limit (Brooker et al, 1974).

3.5 Choice of Materials for Bin Construction.

The choice of material for the construction of a bin does not depend only on its engineering properties but also on its availability locally. Foreign exchange is very scarce for many developing countries including Ghana. As a result, the economics of grain storage favour bins or silos made from materials that will avoid need for foreign exchange. Plywood and concrete are both obtainable locally in Ghana and this would be the prime reason for choosing one or the other of these two materials.

Plywood manufacture has been one of the larger industries in Ghana for some time. Plywoods of different timber species and with various mechanical and physical properties have been produced and used for various purposes. Ghana possesses a good supply of timber from her forest areas across the central part of the country. This includes a wide range of hardwood species. In a recent survey conducted by the Ghanaian Forest Products Research Institute (FPRI), nearly 250 timber species were listed (FPRI Information Bulletin No. 3, undated). The availability of timber coupled with the presence of plywood manufacturing industries favour plywood as a material to be studied for grain storage bins. This is more so when foreign exchange is a limiting factor.

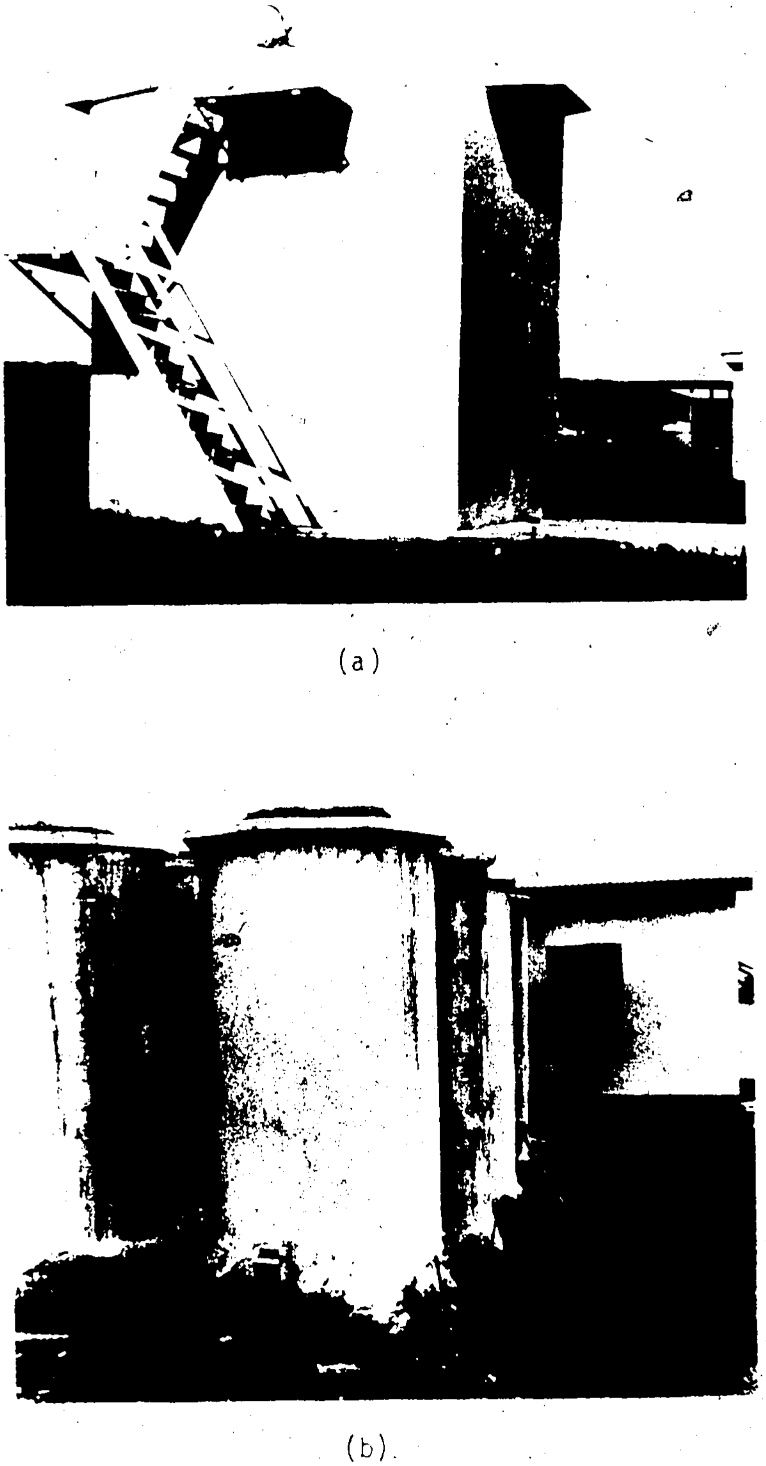
Plywood possesses both lightness and strength and this makes it portable and easy to work. Its ability to bend, within a specified minimum radius of curvature, renders plywood workable into various shapes and forms. A circular resin-bonded plywood silo had been introduced to and used by cooperative societies in the country since 1955 (Forsyth, 1962). Forsyth did not indicate, however, the storage characteristics of the plywood silos. He did note that these silos resulted in a better price being obtained for maize stored in them than that offered for maize stored by traditional methods. A study to establish the storage characteristics of maize in such bins under the hot, humid conditions of Ghana, therefore, is essential.

Concrete, relative to timber, is not so common in Ghana, though it is obtainable locally and widely used for various structures. The caking of stored grain in steel silos in the humid tropics has been a source of considerable loss of valuable produce (Osobu, 1973). Concrete-stave silos have been used with the object of minimizing this problem but results have not always been satisfactory. Moisture penetration through the joints has been found to be the cause of the unsatisfactory use of concrete staves (Osobu, 1973).

Another form of concrete use, for the storage of grain, is in the bush grain storage silo in Nigeria (Rambo, 1973). This is normally constructed of mud bricks on a reinforced concrete floor raised some 300 mm above the ground. The silo is plastered inside and out with a cement-based mix. One of the primary problems encountered has been the cracking of silo walls (Rambo, 1973). A concrete grain storage silo has been developed at the Garu Agricultural Station in Ghana as illustrated in Figure 3.5b (Ghanaian-German Agricultural Development Project, 1974).

A concrete block silo had been used experimentally in Ghana for some years (Forsyth, 1962). These (Figure 3.5a) have been tried at the Crop Research Institute Station at Pokoasi, about 19.3 km north of Accra (personal field trip, 1976). A major problem with this silo has been condensation and caking of grain around the walls (Gyampa, 1976).

The use of reinforced concrete silos for grain storage in the humid tropics has been recommended by various researchers and grain storage specialists. Large concrete silos were recommended, for example for use in Pakistan (Watson et al, 1970a), for bulk grain storage. Watson et al (1970b) and McQuitty (1976) both suggested the use of a


(a)

(b).

FIGURE 3.5: Cement-built bins developed in Ghana.
(a) A concrete silo at the Crop Research Institute Station at Pokoasi.
(b) Cement-plastered bins developed for northern Ghana.

concrete drain pipe with a concrete lid for small farm-sized grain storage bins.

The studies in tropical areas that have been undertaken with concrete and cement-plastered silos, however, have been limited and results inconclusive. Lack of scientific methodology, incomplete observations and subjective rather than objective analysis, together with limited management experience in many instances, make the results of these experiments questionable. Recommendations supporting the use of concrete bins or silos in the developing countries are based, therefore, on published results in developed countries and not under tropical conditions in developing countries.[3]

The acceptance of concrete pipes based on scientific methodology and analysis would render concrete bins a possible substitute for metal bins and also an alternative for most traditional structures. The use of concrete pipes would not necessarily require the setting up of a special factory for their production. There are existing concrete product factories that are producing an assorted range of concrete pipes at present in Ghana. These operations could be expected to manufacture a suitable storage bin should a demand be established in the future for such units.

4. MATERIALS AND PROCEDURES

4.1 Experimental Location and Duration.

The study was performed in an environmental facility of the Department of Agricultural Engineering, University of Alberta, at the Ellerslie Research Station near Edmonton, Alberta. The dimensions provided a room space of about 129 cubic metres. An integrated mechanical unit* capable of heating, cooling and humidifying over a reasonable range provided for the pre-selected conditions of temperature and humidity.

The storage study spanned a period of 24 weeks. It was rted on January 20 and ended on July 7, 1978.

4.2 Materials.

The experimental bins were constructed of either plywood or of concrete. A total of six bins (three of each material) were used for the study. The capacity of each bin was about 1.35 tonnes. This capacity would provide for the storage space required for the cultivation of about 0.8 to 1.6 ha., typical of the majority of farm operations in Ghana. A bin height of 1.52 m was such that they could be filled manually and conveniently from the top by head loads as practiced in Ghana. The inside diameter of the bins was 1.22 m.

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* The heating component of the mechanical unit had a temperature range of about 0°C to 50°C and the cooling component had a capacity to cool 56.6 m^3 per minute of air from 0°C dry bulb (-0.6°C wet bulb) down to -6.7°C dry bulb saturated. The humidifying component had a capacity of 10.9 kg water (steam) per hour.

4.2.1 Plywood Bin.

The type of plywood used for the bins was Douglas Fir plywood. It was a commercial grade classed as good two sides. The walls of the bins were constructed of 6.35 mm nominal panel thickness. The floors of the bins, however, were constructed of 12.70 mm nominal panel thickness. The dimensions and details of the bins are illustrated in Figures 4.1 and 4.2.

The joints were glued and nailed. The type of glue used was Weldwood's* Resorcinol Waterproof Glue. This was rated as providing permanent bonds which withstand outdoor exposure, cold or boiling water, heat, mould, solvents, acids and alkalis.

The top edge of the bin wall and the contact areas of the cover were lined with strips of rubber cut out from used inner tire tubes. This particular arrangement (Figure 4.3) provided an almost air-tight seal when a load was added to the top of the cover. A better seal, however, was accomplished with the insertion of foam rubber between the contact areas of the bin and its cover.

4.2.2 Concrete Bin.

The concrete bin used for the storage study was an adaptation of concrete pipes. These were manufactured by Vanguard Concrete Products Limited in Edmonton. Each bin was created from a two-piece pipe. The two barrels, as shown in Figure 4.4, were cement plastered together to form a bin as shown in Figure 4.5.

The top and bottom barrels weighed 829 kg and 1597 kg

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* Weldwood Glues are manufactured by Weldwood of Canada Limited, Vancouver, British Columbia V6B 3V8.

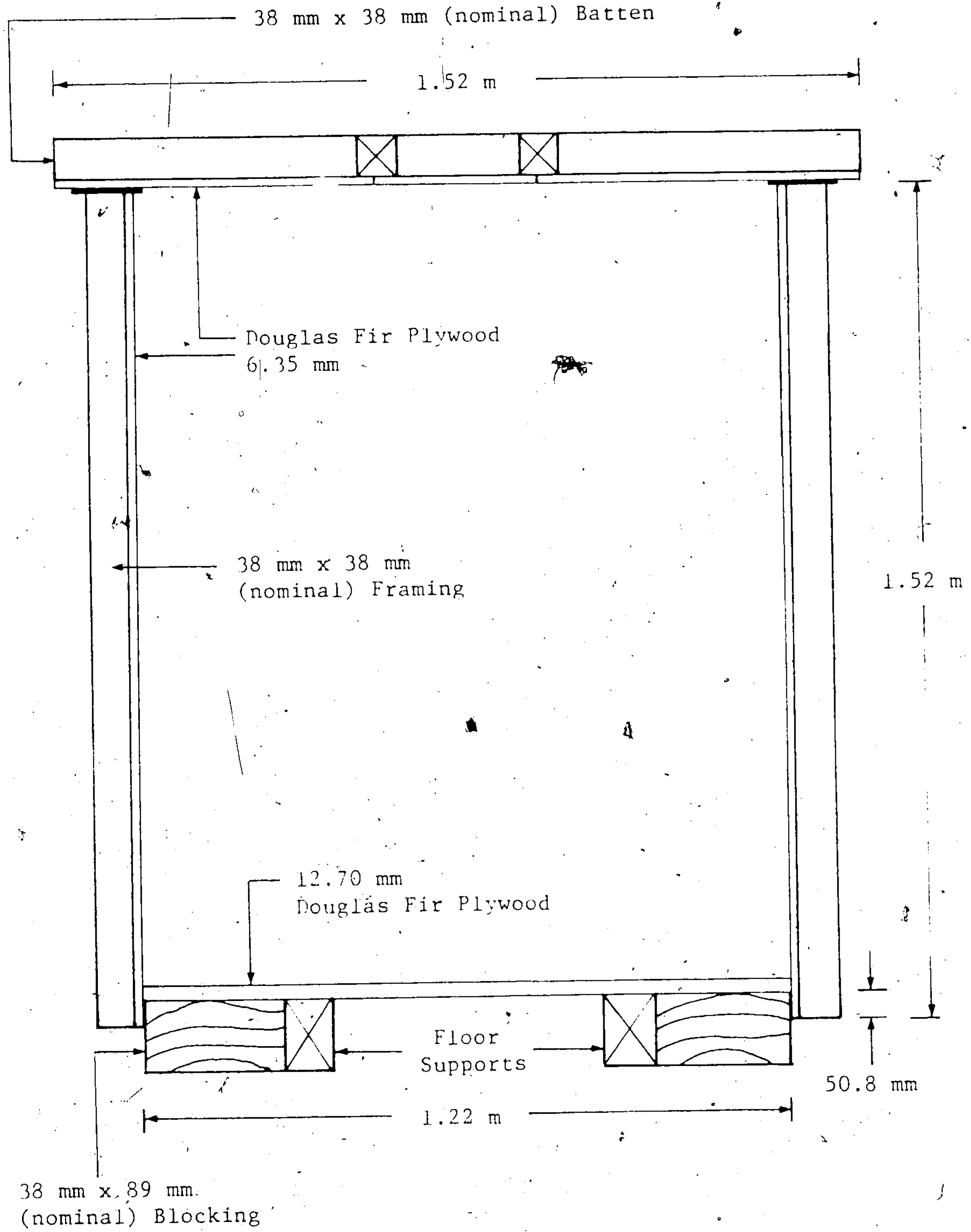

FIGURE 4.1: Vertical section of a plywood bin.

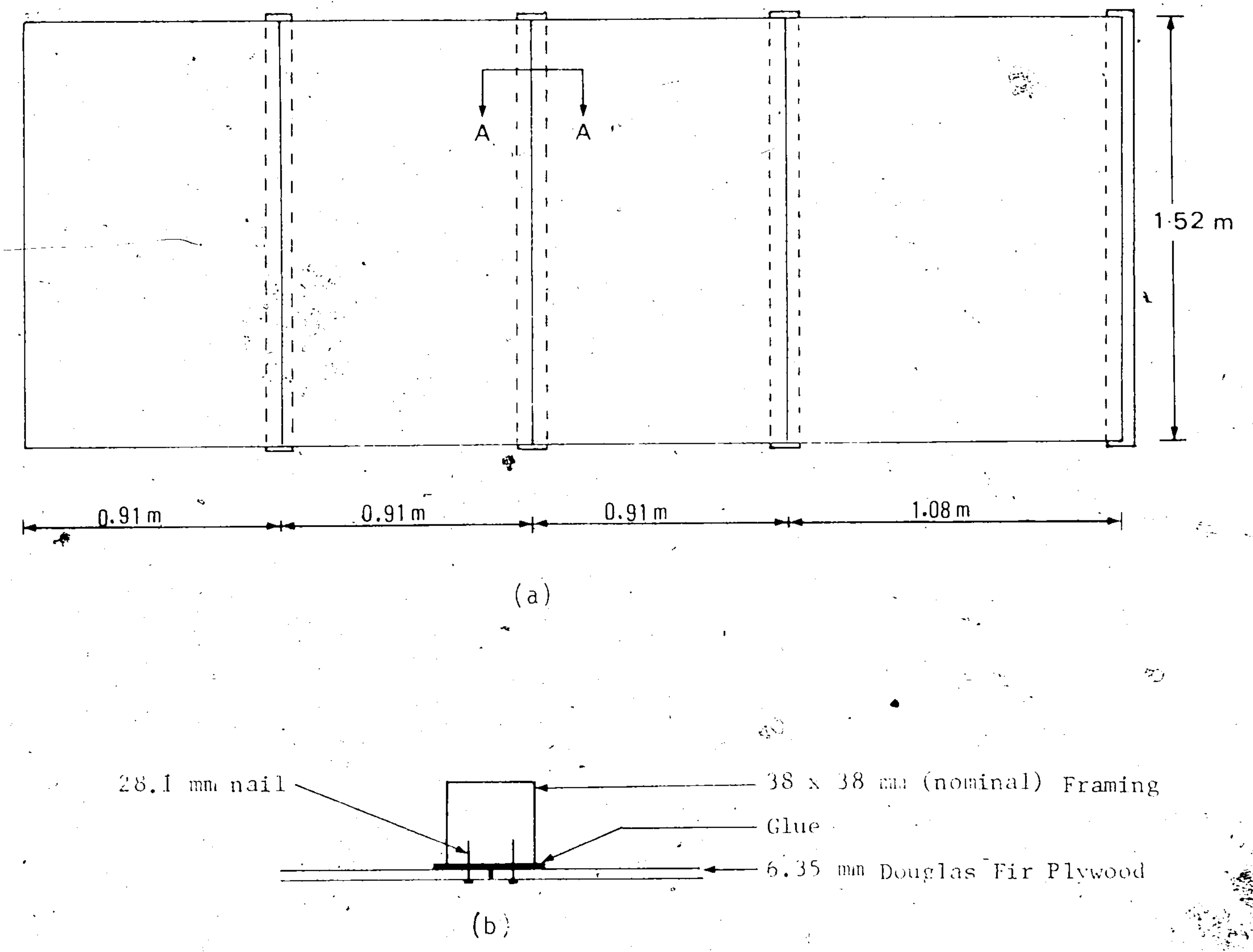

FIGURE 4.2: (a) Plywood bin wall panel (inside face).
(b) Section A-A. Jointing detail.

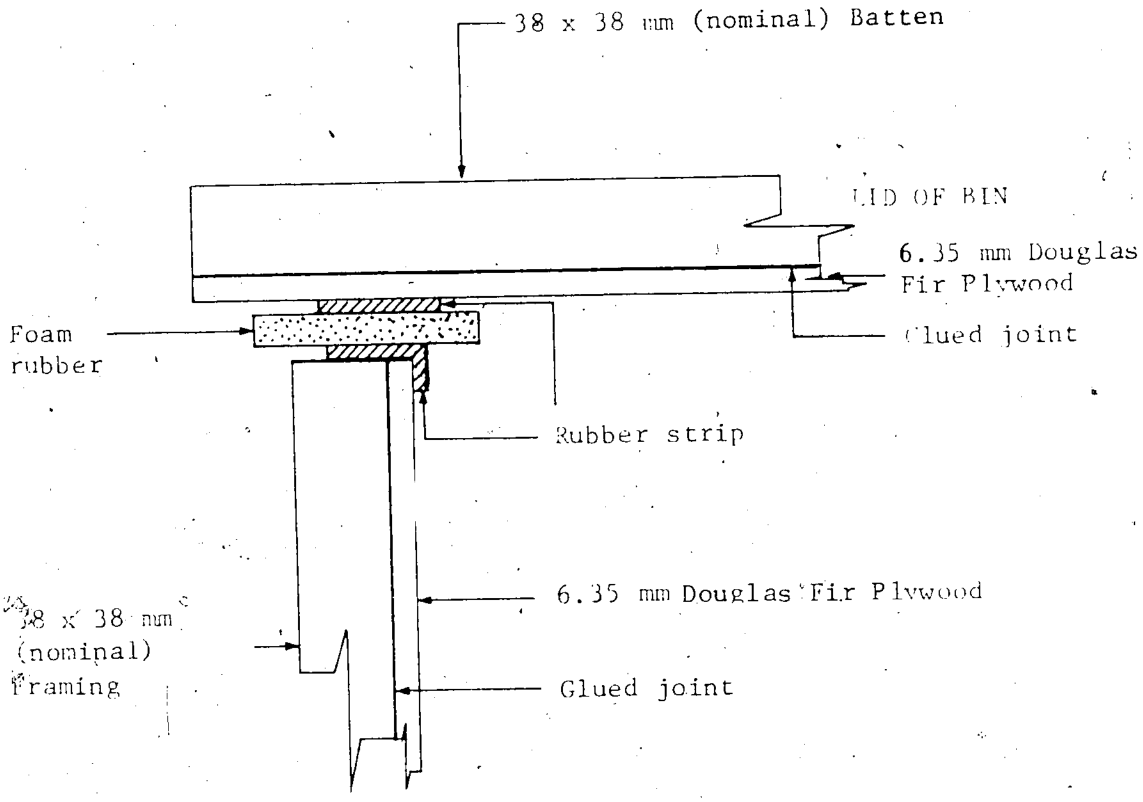

FIGURE 4.3: Detail of seal between plywood bin wall and the lid.

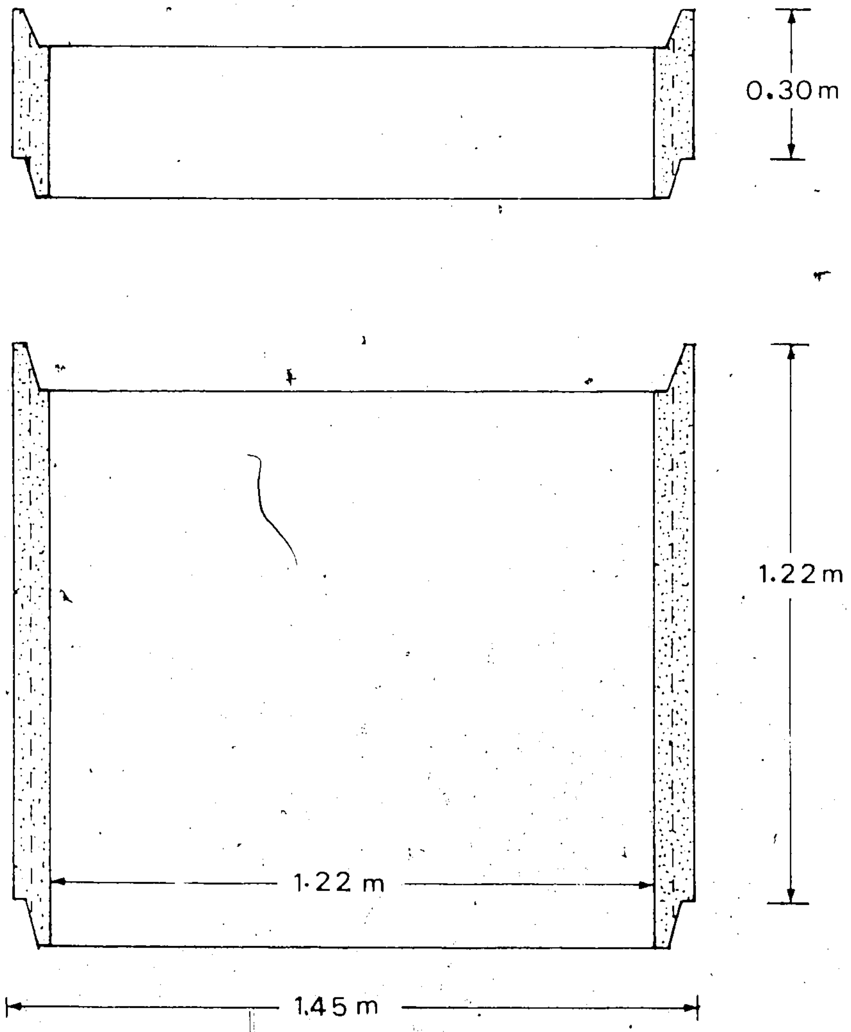

FIGURE 4.4: Vertical sections of the two barrels which formed a concrete bin.

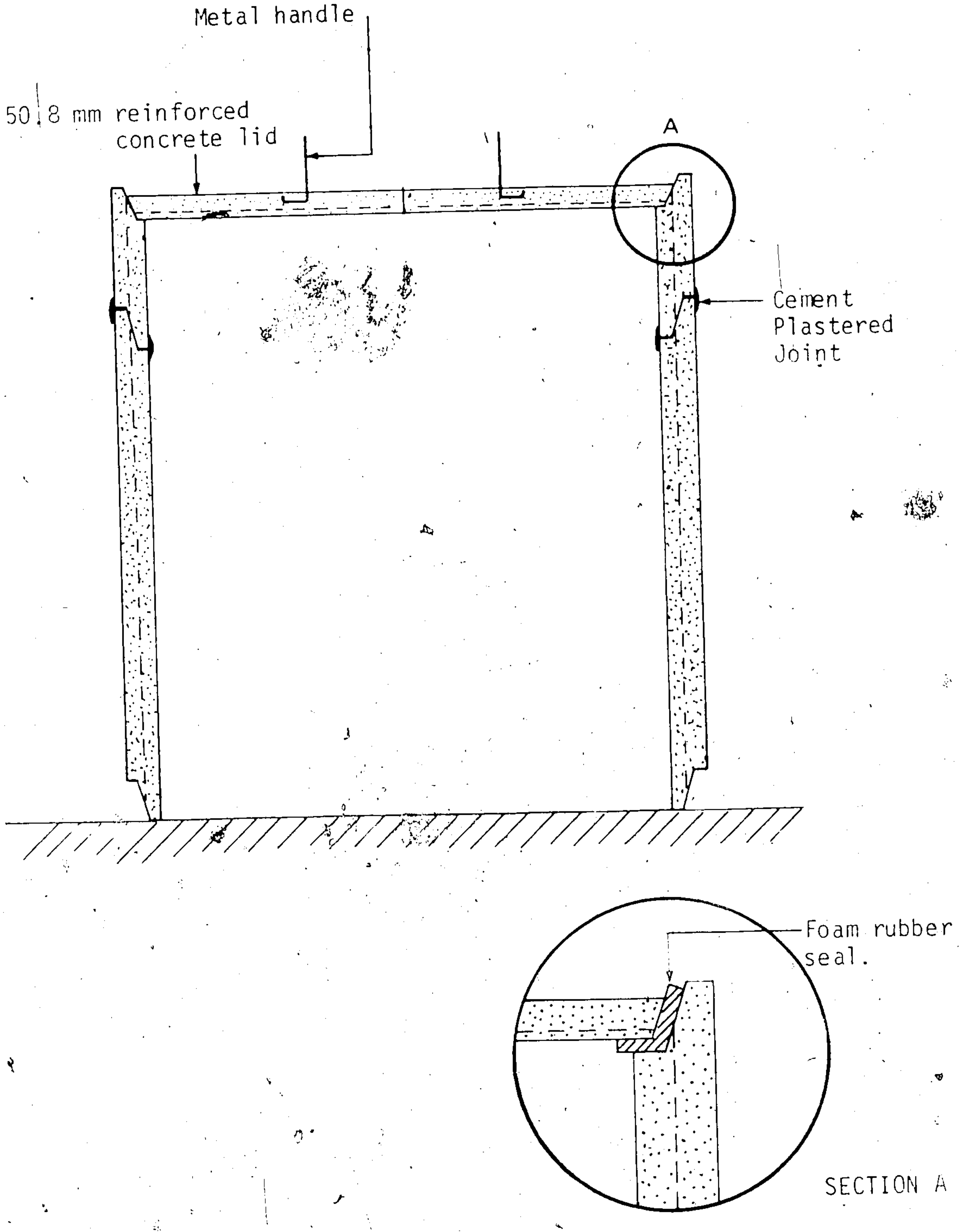

FIGURE 4.5: Vertical section of a concrete bin with section A showing the detail of the joint between the wall and the lid.

respectively. These were incidentally rejects from the factory.* The defects causing the rejection were mainly minor cracks or slumps in the walls. These pipe rejects, however, possessed the strength to resist with ease the vertical and lateral stresses exerted by the grain. The concrete bins were set on the floor of the environmental room. The floor of the room thus formed the floor of the concrete bins. The lids of the concrete bins were 50.8 mm thick, reinforced concrete. These were in two halves. Each half was fitted with metal handles to facilitate easy opening and closing of the bin.

4.2.3 Ambient Temperature, Solar Radiation, and Relative Humidity.

Ghanaian environmental conditions of temperature and solar radiation effects were simulated by the use of tungsten-filament infrared lamps.** These were rated as efficient radiant-energy heat sources. Each lamp was rated at 250 watts and had a range of wavelengths from about 300 to 1600 nanometers. The heat lamps were set on eight rectangular wooden frames. The frames were hung over the bins, which were arranged as shown in Figure 4.6, at an angle of about 45 degrees to the horizontal (Figure 4.7). The arrangement of the wooden frames was such that they had an inverted "V" configuration. There were 12 heat lamps per wooden frame. There were four rows of lamps and each row had three lamps.

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* The Vanguard Concrete Products Limited manufactures all pipe sections to A.S.T.M. specifications. Defective pipes or pipes that do not meet the A.S.T.M. specifications are rejected and crushed.

** These were quartz tungsten halogen lamps obtained from Canadian General Electric. The radiant energy produced by these lamps is distributed in a continuous spectrum, that is, from near ultraviolet into the far infrared spectrum.

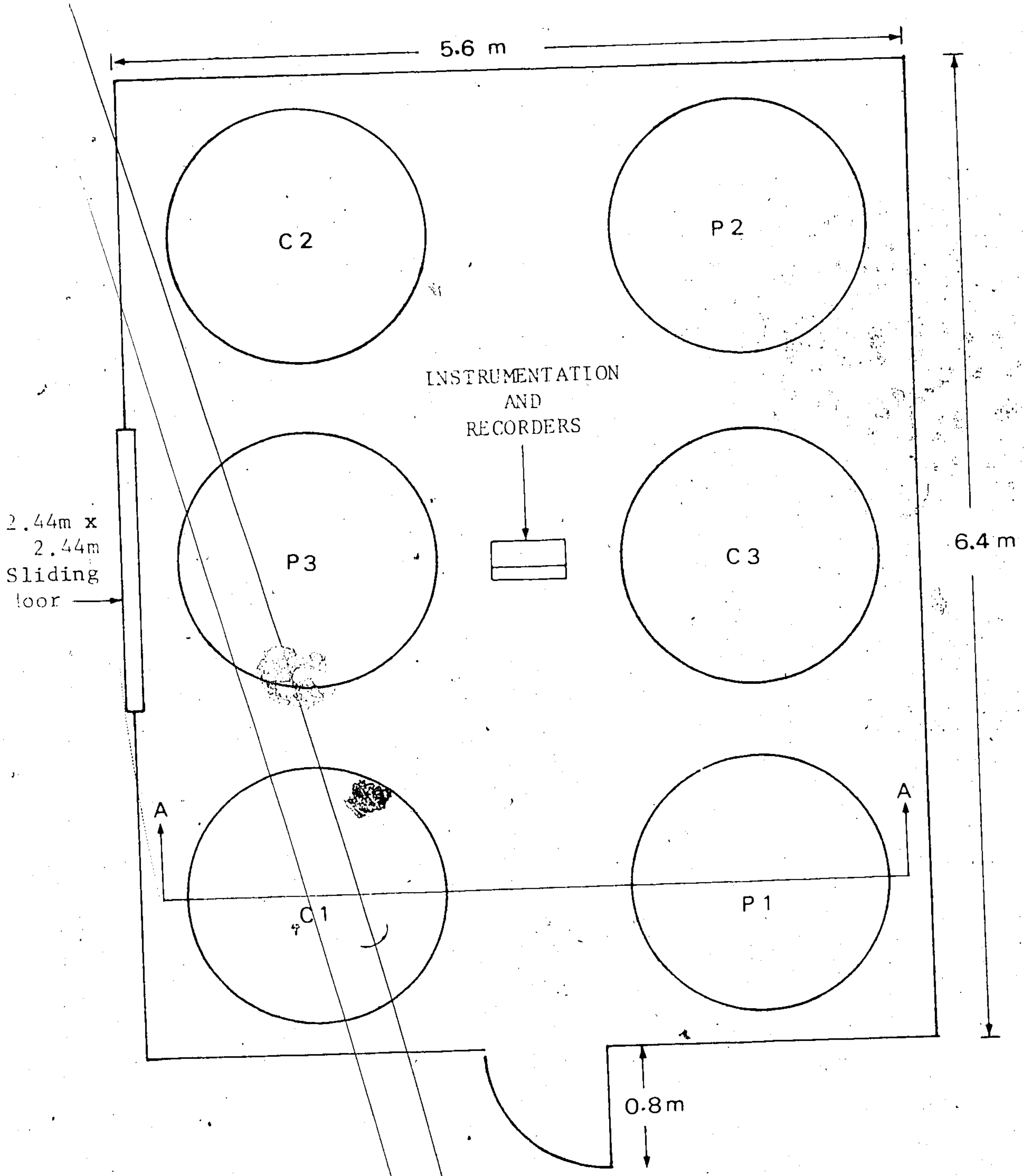

FIGURE 4.6: Arrangement of bins inside the environmental room with instrumentation and recorders in the centre of the room. The plywood bins have been marked P1, P2, P3, and the concrete bins as C1, C2, C3.

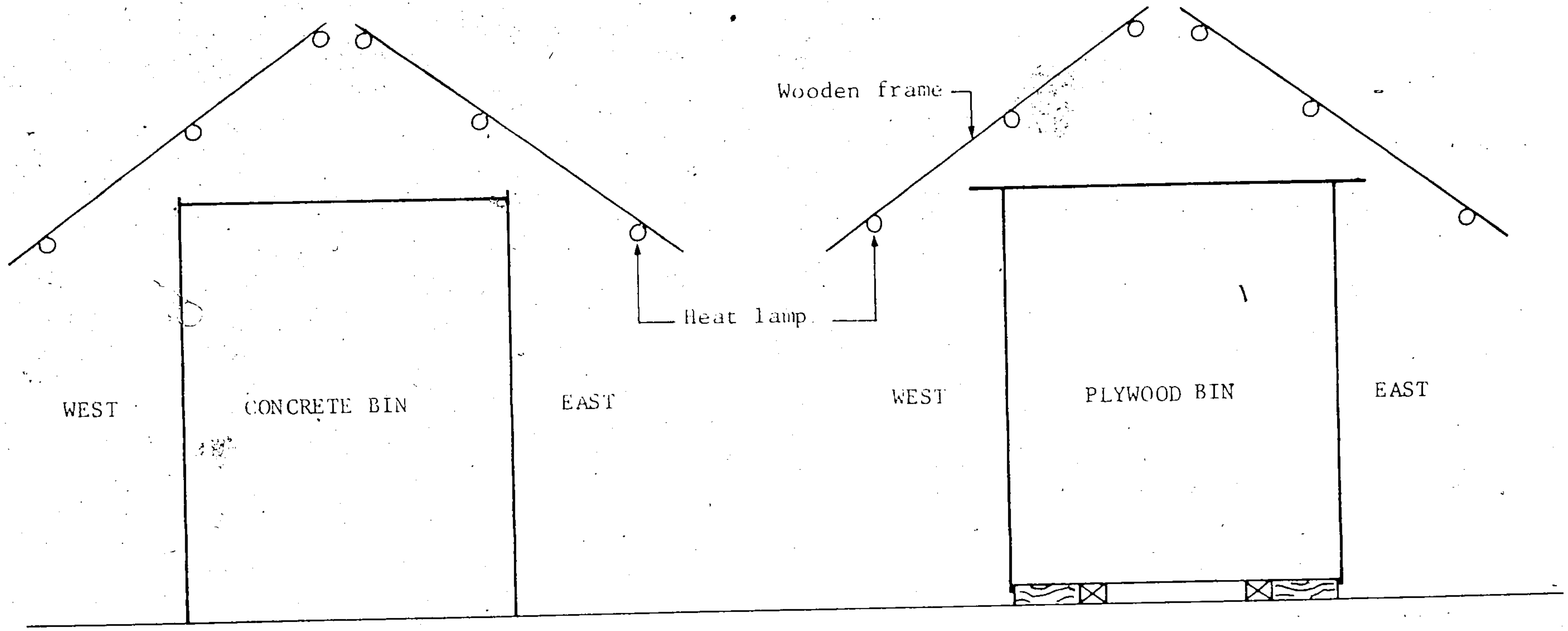

FIGURE 4.7: Section A-A. Bin and heat lamp arrangements inside environmental room.

The desired relative humidity of the room was achieved by the use of the humidity component* of the integrated mechanical unit. A humidity sensor in the environmental room controlled automatically the level of humidity preselected for the environment.

A solar energy meter, "Phebus 1" insolometer**, was used to measure the simulated solar radiation effect. Ambient temperature and relative humidity were measured by a Belfort Hygrothermograph.***

4.2.4 Grain Bulk Temperature.

Copper-constantan thermocouples were used for temperature measurements. Each bin had twenty-four thermocouple points located in the grain bulk. There were three horizontal levels of thermocouples, with 8 positions at each level or depth (Figures 4.8 and 4.9). The thermocouples were held firmly in place by strings attached to wires and fastened to the floor of the plywood bin by staples. In the case of the concrete bins, masking tape was used to hold the strings firmly to the concrete floor. On top of the grain bulk, the thermocouples were set in holes in crossed wooden frames nailed to the bins (Figure 4.11). This ensured that the thermocouples were not displaced at the time of filling the bin or by sampling when probing into the grain mass during the experiment.

Radial spacings of thermocouples on each level were 15.24 cm and 30.48 cm from the centre (Figure 4.10). A total of about 1500 m of thermocouple wire were used. The thermo-recorder was a 24-channel Honeywell unit (Figure 4.12).

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* This was trade marked as "Dri-Steem", model number 5A.

** "Phebus 1" is a manufacturer's trade mark. It is manufactured by Valley Products and Design, Inc., Pa., U.S.A. 18337.

*** Belfort Instrument, serial no. 4939. Manufactured by Belfort Instrument Company, Baltimore 2, Maryland, U.S.A.

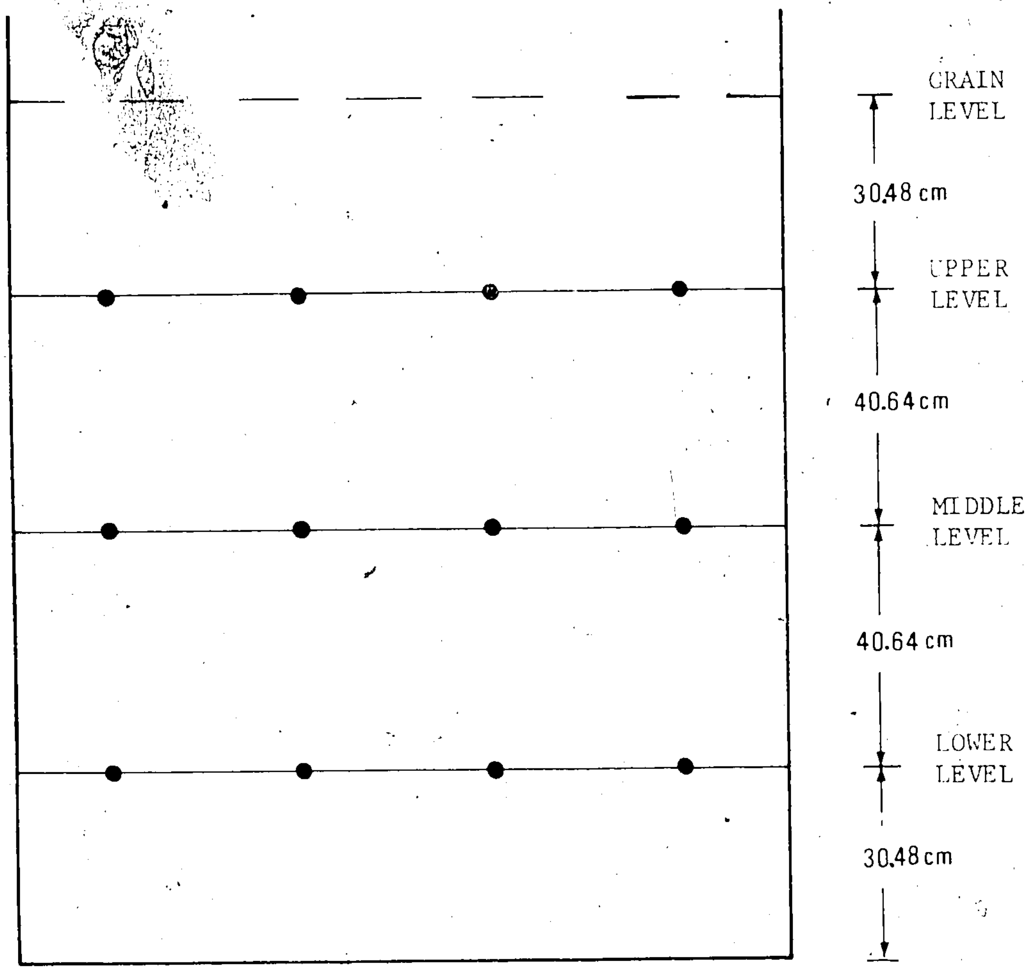
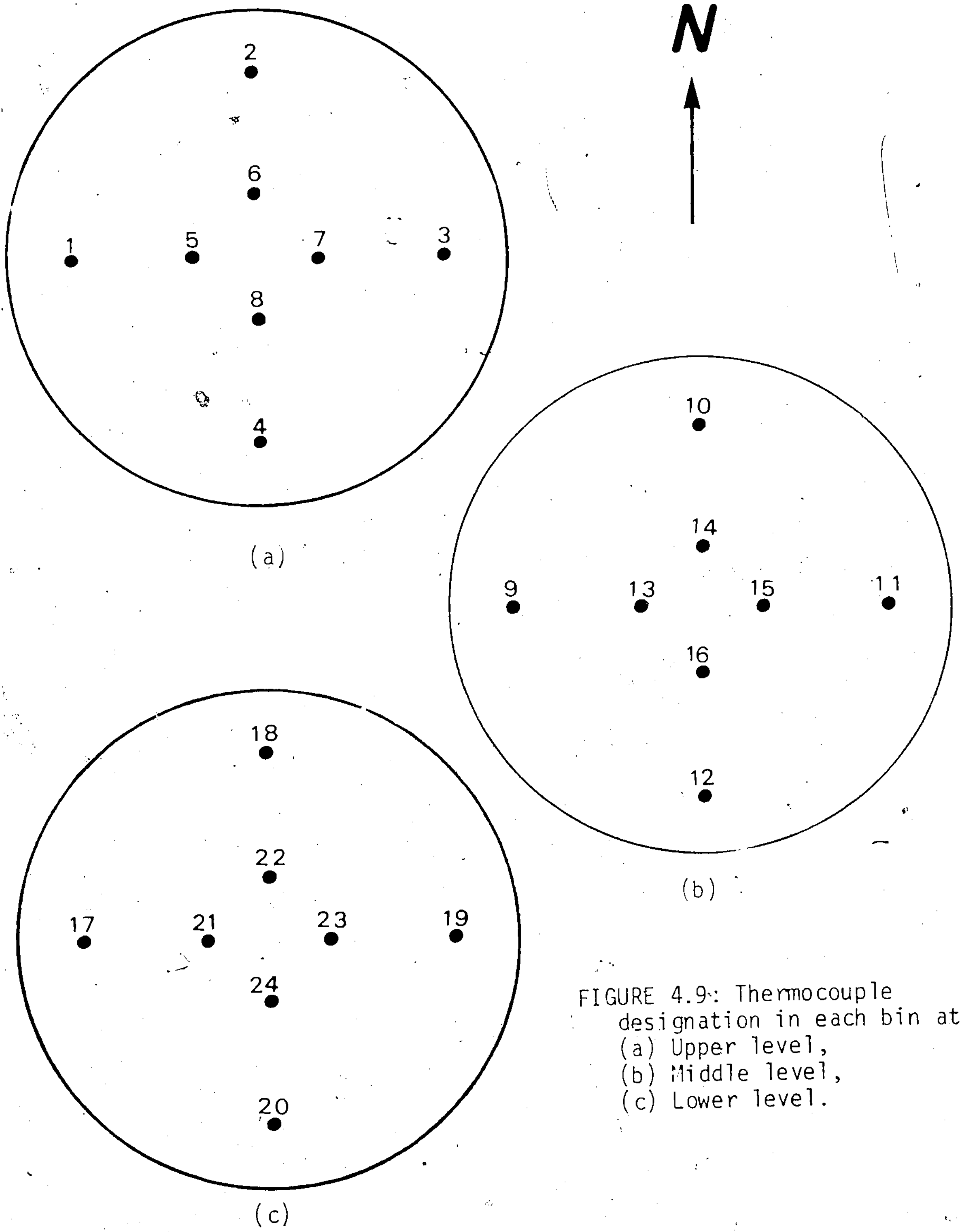


FIGURE 4.8: Vertical section along the diameter of a bin showing the relative positions and levels of thermocouple points inside the grain bulk.



(a)

(b)

(c)

FIGURE 4.9: Thermocouple designation in each bin at:
(a) Upper level,
(b) Middle level,
(c) Lower level.

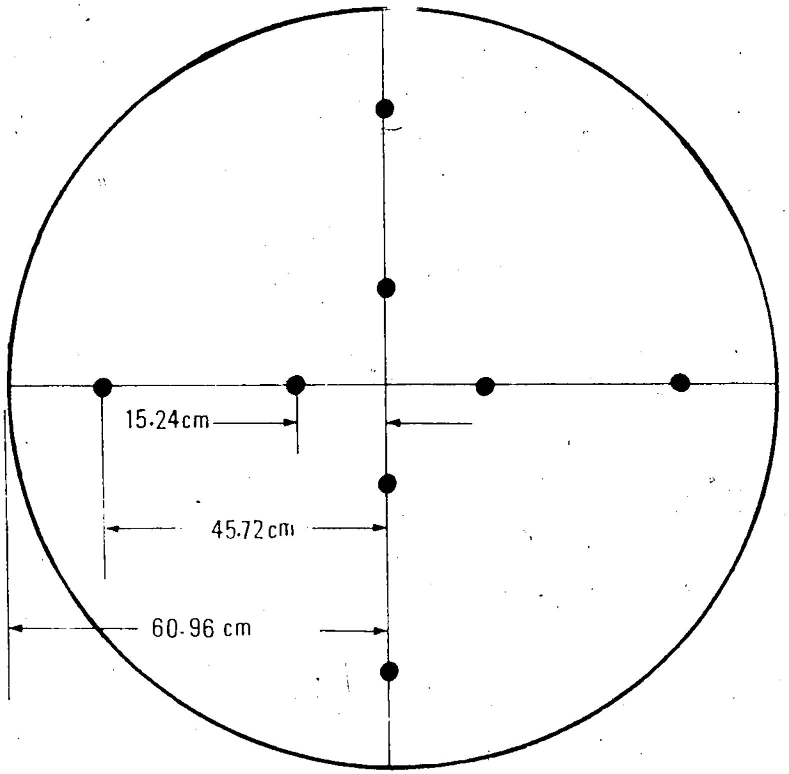


FIGURE 4.10: Radial spacing of thermocouples at each level.

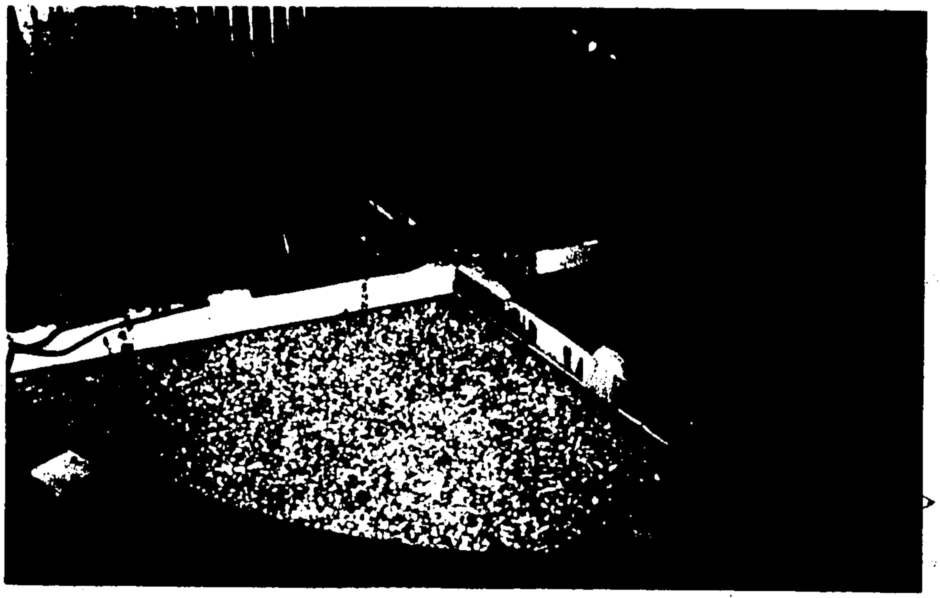


FIGURE 4.11: Positioning of crossed wooden frame on top of grain bulk, and the insertion of thermocouple wires through the frame to hold the wires in position.

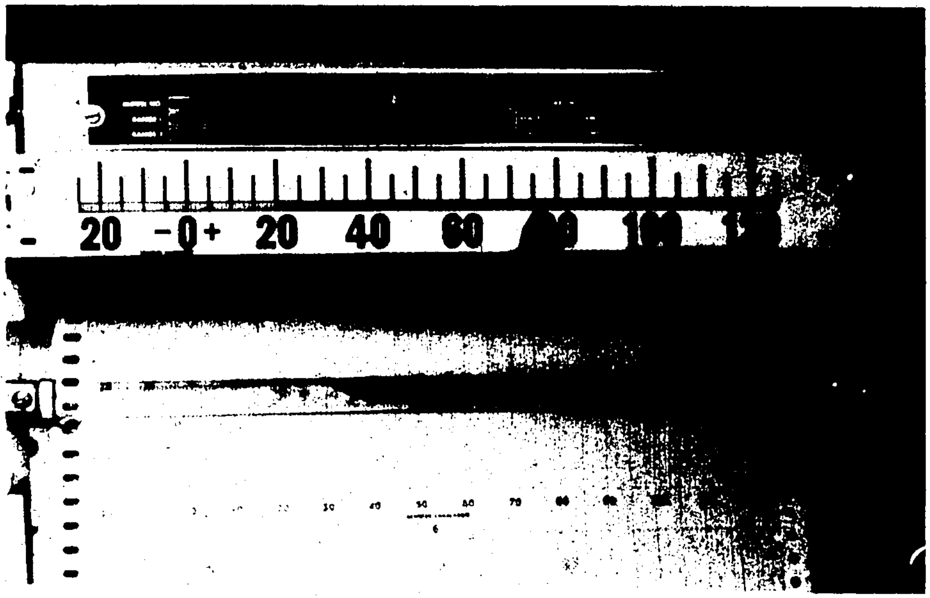


FIGURE 4.12: The temperature recorder with graduations in degrees Fahrenheit.

4.2.5 Experimental Maize.

The grain used for the experiment was Grade II yellow maize. This was obtained from the United States of America through the Shur-Gain Company in Edmonton. The initial moisture content of the grain was about 12.0% at the time of purchase. Total weight of grain used was about 8.1 tonnes.

A germination test performed with 200 whole kernels indicated an initial 45% germination rate. This was an indication that the grain might have been either artificially dried at very high temperature, handled (mechanically) excessively, or in store for some time before it was obtained.

4.3 Experimental Procedures.

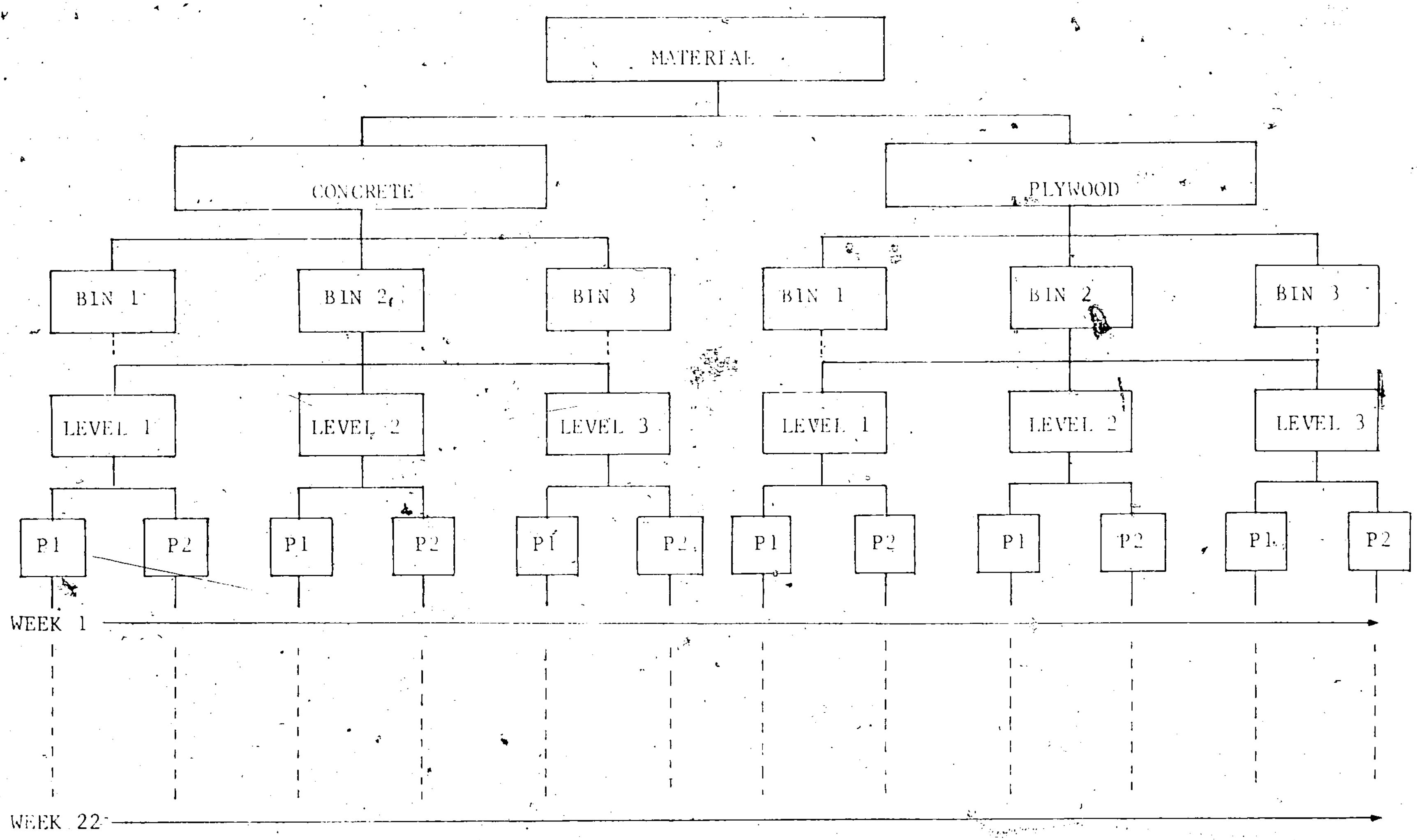
4.3.1 Experimental Design.

The experimental design for the statistical analyses of grain temperature and grain moisture involved three bins of each of two types of materials (plywood and concrete). Within each bin were three levels and two positions. Measurements were made for each treatment combination for each of twenty two weeks. The sources of variation, therefore, were material (n = 2), bins within material (n = 3), levels (n = 3), positions (n = 2) and weeks (n = 22). These have been illustrated in Figure 4.13.

A multiway analysis of variance was used for analyzing the data.

4.3.2 Simulation of solar radiation, temperature and relative humidity.

The three physical factors of solar radiation, ambient



P = position (radial spacing)

FIGURE 4.13: The experimental design for one replicate.

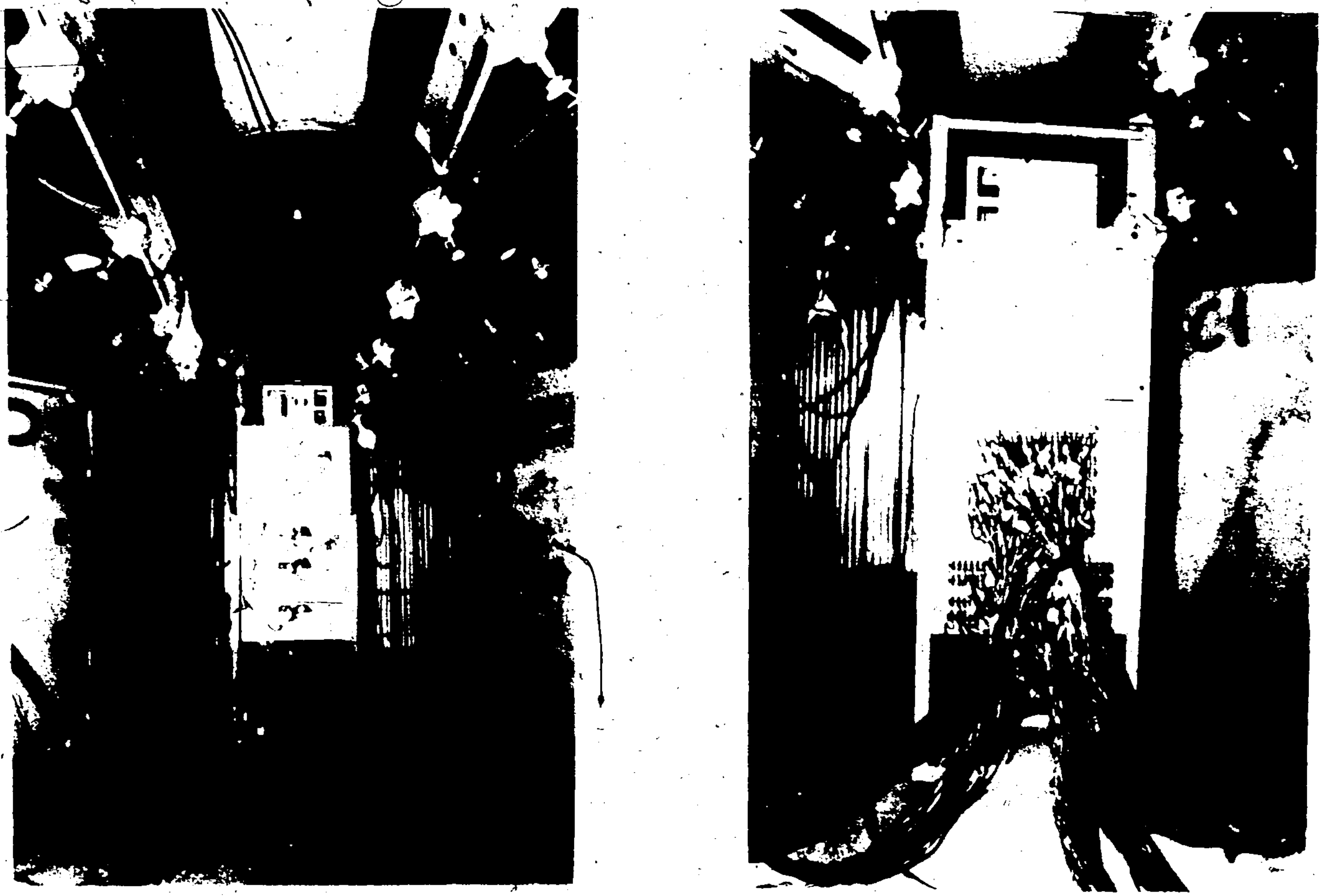
dry bulb temperature and relative humidity were simulated. The objective of the simulation was to approximate conditions for Kumasi, Ghana, (area between latitudes 6 and 7°N) for the months of July to December.

Ambient temperature was achieved by the use of the heat lamps that were suspended over the bins (Figure 4.14). The two sets of lamps over each row of bins were switched on and off alternatively. The set on one side (designated east) was on, as morning sun, at 8:00 a.m. and off at 12:15 p.m. The other set on the opposite side (designated west) was on, as afternoon sun, from 12:00 noon to 4:30 p.m. A relay switch incorporated in the lighting circuit and connected to a timer produced the sunrise and sunset effect of the day. Night and early morning decreases in temperature were effected automatically by the cooling and heating units set to the required temperature.

Solar intensity values were simulated for the months of July to December for the Kumasi area, Ghana (Table 4.1). These values were obtained from computerized energy calculations (A.S.H.R.A.E., 1971). The calculations assumed a zero percent overcast skies. A mean of 11.7 sunshine hours per day was assumed.

During the experimental period, the heating of the environment, that is, the temperature rise during the day, was effected by the heat lamps and not by the integrated mechanical unit. Heat radiated from the lamps sufficed to raise the temperature to the desired limits.

Desired relative humidity conditions were obtained by a fine spray of moisture (steam) into the air from the humidity device incorporated in the mechanical unit. The humidifier was set on and off automatically according to a preset humidity level on a humidistat.



(a) (b)

FIGURE 4.14: Relative positions of experimental units.
(a) The front view of thermocouple recorder.
(b) The back view of thermocouple recorder.

TABLE 4.1 SOLAR INTENSITY VALUES OBTAINED FROM COMPUTERIZED ENERGY CALCULATIONS FOR KUMASI, GHANA (A.S.H.R.A.E., 1971)

	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
			[mW/cm^2]			
Morning	6.12	6.28	6.95	7.44	7.66	7.84
Afternoon	6.31	6.52	6.98	7.39	7.79	7.76
Maximum	7.49	7.66	8.09	8.52	8.84	8.90

4.3.3 Solar Intensity, Temperature and Relative Humidity Measurements

Ambient dry bulb temperatures and relative humidity were recorded by a hygro-thermograph. This recorded the diurnal temperature and humidity variations. The simulated solar intensity effect on a flat horizontal surface, that is, bin top, was measured by the solar energy meter. Measurements were taken at various points on top of a bin and the mean was taken as a representative solar intensity value.

The temperature within the grain bulk was measured by the 24-channel Honeywell Recorder with a range of -32°C to 52°C (Figure 4.12). The bins were filled with grain with an initial temperature of about 7°C. The maize was held in all the bins for about one week, under room temperature conditions of about 23°C, before the grain bulk temperature recordings were started. This was necessary to allow the somewhat chilled grain to attain a level of thermal equilibrium. Also, it provided time to get the 144 thermocouple wires hooked up to the recorder

(Figure 4.14).

4.3.4 Creating the Initial Moisture Content of the Maize for Storage.

The characteristics of naturally moist and remoistened grain are not significantly different (Hustrulid, 1963). The alternative method of direct water application of the grain was used, therefore, to increase the moisture content.

The maize as delivered by the supplier was found to have a moisture content of about 12.0%, wet basis, which was considered too dry. For the purpose of the experiment, an initial moisture content of between 15 to 17 percent was desired. This range corresponds to the typical moisture content of maize in Ghana at the time it goes into storage on farms. The moisture content of the maize, therefore, was raised to within the desired moisture range. The amount of water to be added was calculated using the following equation (Harrison, 1969):

$$\Delta_w = M_w - \frac{M_w'(1 - M_w)}{(1 - M_w')} \qquad (1)$$

where Δ_w = amount of water to be added, lb

M_w = original moisture content of grain, %

M_w' = desired moisture content of grain, %

The water was sprinkled manually onto the kernels at the intake end at the bottom of the hopper of a New Holland farm grain mix-mill. The moistened kernels were augered up and down into the holding tank. The grain was mixed as it was augered into the tank. The moistened grain was held in the tank for about 24 hours and then unloaded into the bins by an extendable auger attachment to the mixer. Moisture addition and, therefore, filling of the bins were done in stages. The reason for this approach was that the amount of grain to be moistened at one time was limited by the size of the mixer.

4.3.5 Moisture Measurement.

The air-oven method of measuring moisture content of grain was used (USDA, 1971). About 15 to 16 gm of kernels were oven dried for 72 hours at a temperature of about 103°C. The samples for the initial moisture content analysis of the grain were taken at the time of loading the bins. The individual samples so taken were mixed thoroughly and, from the bulk, 20 samples were analyzed for moisture. Each sample weighed between 15 and 16 gm.

Samples again were taken after 12 and 24 weeks of storage, from each of the 24 thermocouple locations in each bin. Sampling from these points was achieved by the use of a sampling probe. In addition to these, two samples were taken also from the surface grain. These were collected at the centre and from the periphery.

At the end of the storage period (24 weeks), more samples were taken from each bin in addition to the 26 samples. The grain was removed carefully in layers by vacuum to observe changes in the condition of the grain with depth. Samples were taken from the wall grains, in between the thermocouple points and also from grain on the floor of each bin. Sampling was at all the three thermocouple levels. Each sample taken weighed about 130 gm.

4.3.6 Microbial Analysis.

The initial microbial analysis was carried out on 200 kernels taken from a representative sample of the grain bulk. Five seeds were spaced out on an Agar-Dextrose medium in petri-dishes. Forty petri-dishes, therefore, were used for the culturing of the fungi. The incubation period was from seven to ten days at a room temperature of about 22°C.

After the incubation period, the kernels were examined under a microscope and the species of fungi growing on them identified. The number of maize kernels showing the various fungi was recorded.

Microbial analyses again were performed on the samples taken after the 12 and 24 weeks of storage at each thermocouple location. For these analyses, 50 seeds of each of the 26 samples were incubated and examined as described for the initial sample analysis.

5. RESULTS AND DISCUSSION

5.1 Visual Observations and Assessment of Maize Quality after Storage.

5.1.1 Plywood Bin.

During the total storage period of 24 weeks, the plywood bins were opened twice for sampling by probing from the top. The first sampling was at the end of the twelfth week. The second sampling, done in the same way as the first, was at the end of the experiment.

The condition of the top kernels was considered good, by visual observation only, on the first sampling schedule. The kernels appeared clean and quite dry and loose. Probing down to the lower depths or layers for samples was not difficult though it required some force to push the probe down through the mass of grain. At the end of the 24 weeks of storage, the kernels were quite loose, in most areas, but less free flowing than the initial grain in all the three plywood bins. The grain, however, was slightly musty. Mould infection was noticeable on the kernels in the peripheral areas on top of the grain, around the walls and on the floor (Figure 5.1). The kernels in general had been discoloured slightly. This discolouration was noticeable only when the kernels were examined very closely.

Probing the grain bulk for samples at the end of the experiment was more difficult than at the first sampling. This might be an indication of compaction of the grain (caking) as a result of moisture accumulation at the lower depths within the grain mass.

On the whole the condition of the grain in the plywood bins might be regarded as moderate with respect to the initial sample or bulk. Visual assessment rated it as being not good for human

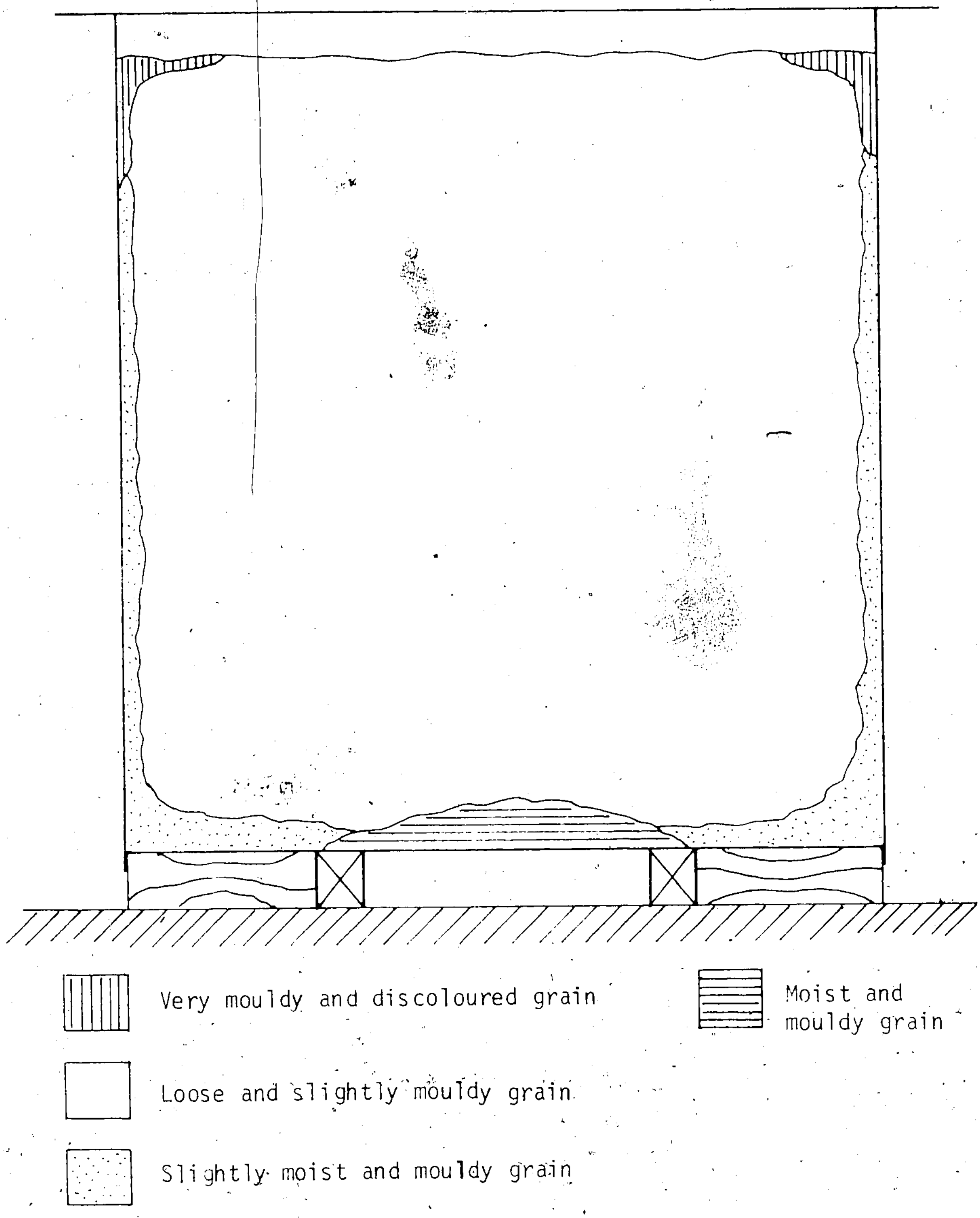


FIGURE 5.1: Observed condition of maize kernels at various areas within the plywood bins at the end of 24 weeks of storage.

consumption, but acceptable perhaps for livestock feed.

The top 30.5 cm of the grain was generally clean, dry and loose. It was not much different in physical form and total appearance from the original maize sample.

On the eleventh day of the experiment, the humidifying unit malfunctioned and sprayed out hot water instead of steam. The water seeped through the lid of plywood bin 1, which was located directly below the humidifier, and soaked the grain inside the bin. Consequently, the bin was emptied immediately and refilled with fresh maize from the same original stock. The refilled bin consequently was 11 days behind the other bins throughout the duration of the experiment.

5.1.2 Concrete Bin

The schedule for opening the concrete bins was the same as described for the plywood bins. The condition of the grain was musty on the first opening and sampling. The top kernels were already in an advanced stage of mustiness. The degree of mustiness, however, decreased towards the centre. The grain bulk was very difficult to probe for samples, particularly from the middle and lower layers.

By the end of the storage experiment, the grain in all the three concrete bins was extremely musty. Mould infection on the top kernels was very conspicuous. There was a layer of about 2.5 cm of caked kernels on top of all three bins. Below this crust was a layer of relatively loose kernels to a depth of about 30.5 cm. Below that depth, the grain was moist and caked (Figure 5.2). The degree of caking increased towards the walls. Caking along the walls was about 5.0 cm thick and stretched vertically to the total depth of the bin. There were two distinct layers of caked grain on the periphery. An immediate

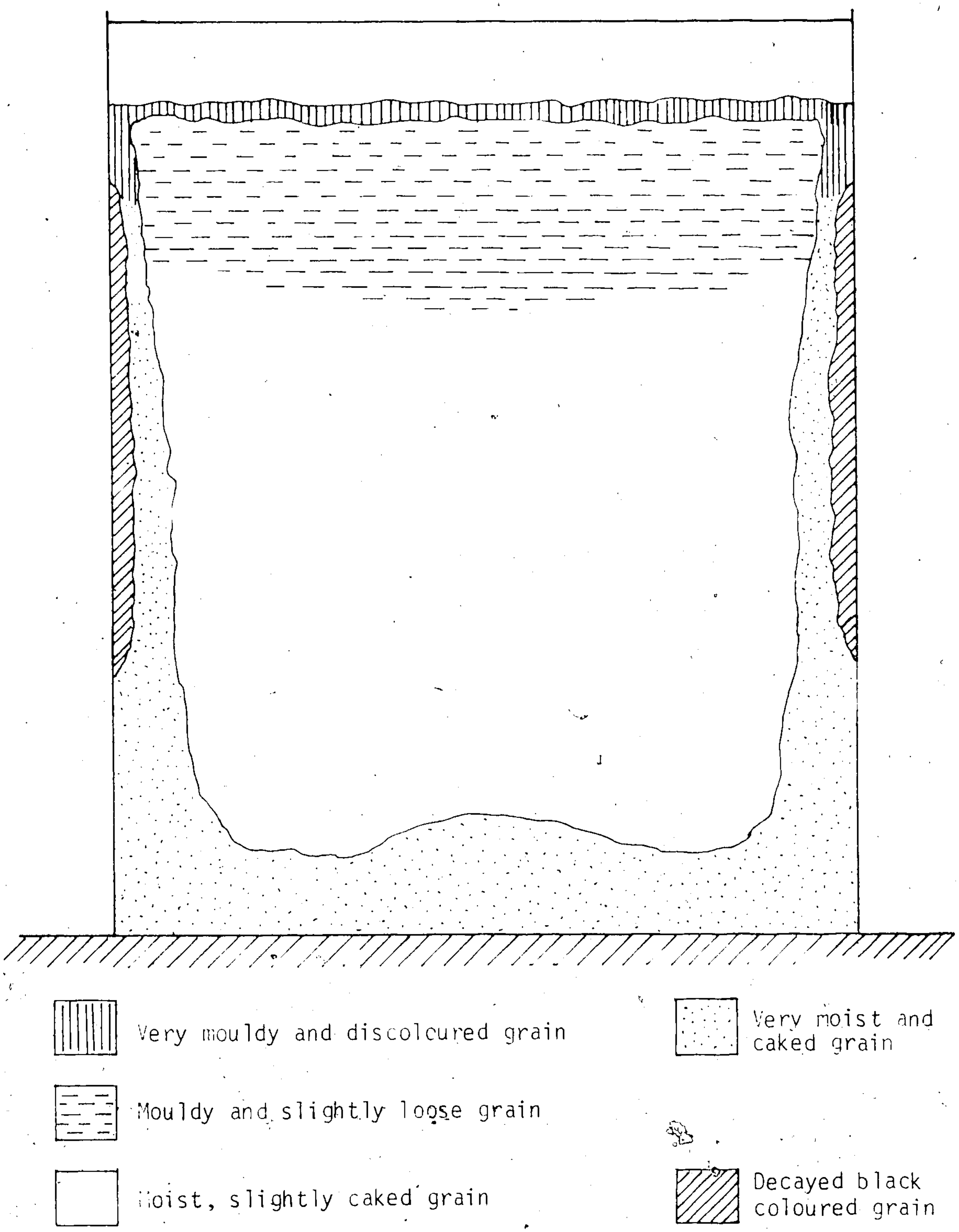


FIGURE 5.2: Observed condition of maize kernels at various areas within the concrete bins at the end of 24 weeks of storage.

layer 2.6 cm from the wall consisted of a black coloured mass of kernels in a very advanced stage of decay that was virtually "glued" to the walls of the bins. The next layer was lighter in colour but also caked and decayed. The caked and decayed kernels in the peripheral areas formed a sort of shell around the grain bulk inside the bin. The thickness of the shell increased with depth. For instance, the shell thickness was about 7.6 cm at a depth of about 30.5 cm. Below this depth, the thickness of caked kernels could be 15.3 cm or even more. The peripheral layer of black-coloured and decayed kernels stretched down to a depth of about 76.2 cm. Below this depth, the kernels did not stick as readily to the walls.

There was a presence of a sharp, irritating and lachrymatory odour from the grain inside the concrete bins. The smell of ammonia was very strong in the peripheral areas of the bin. Oxygen concentrations within the grain mass might have been very limited as a result of respiratory activities of the grain, microflora and insect pests. An almost anerobic environment could have existed within the grain bulk. In anaerobic metabolism and in the presence of certain species of bacteria, a simple decomposition reaction may be given as:

$$C_6H_{12}O_6 \longrightarrow 3CH_4 + 3CO_2 \qquad (1)$$

In a more generalised relationship, not all organic matter will be broken down or decomposed as in equation (1). The stoichiometric equation for the ideal process can be written as (Rich, 1973):

$$C_aH_bO_cN_d \longrightarrow nC_wH_xO_yN_z + mCH_4 + sCO_2 + rH_2O + (d-nz)NH_3 \qquad (2)$$

where $s = a - nw - m$,

$r = c - ny - 2s$,

$C_aH_bO_cN_d$ = undigested original organic matter, and

$C_wH_xO_yN_z$ = residual non-digestible organic matter.

The reaction demonstrated in equation (2) provides sufficient evidence that ammonia may indeed have been produced during the decaying process inside the concrete bins. The grain in the lower depths of the bin and on the floor was very moist and in the process of caking as illustrated in Figure 5.2. The visual assessment of the grain in the concrete bins rated the maize completely unfit for human or animal consumption.

5.1.3 Grain Pests

There was no observed evidence of insect pests in the original maize sample. A grain pest, the rusty grain beetle (Cryptolestes ferrugineus), was noticed in all bins during the first sampling. The population of the pest was relatively very small and only in localized areas in the top surface grain and in a few places within the grain bulk. Infestation rate or pest population, however, was very high soon after the first sampling, that is, after the twelfth week. These grain beetles spread all over the experimental room during and after the fourteenth week of storage.

By the end of the storage period, the pest population had decreased surprisingly within the room. Despite this decrease, the number of pests on the inside walls of the bins and on the surface grain was relatively high. Scattered pest populations were noted in the grain within 30.5 cm from the surface. Few pests were observed in the lower depth and floor of the plywood bins. In both plywood and concrete bins, they congregated in localized areas where grain was in a very mouldy and moist condition. The accumulation of grain beetles in such areas has been attributed to a klinokinectic response to humidity (Surtees, 1965) and to olfactory stimuli from one or more volatile compounds in the fungi or by-products of the fungi (Dolinski and Loschiavo, 1973).

5.1.4 Microflora

Initial microbial analysis of the grain indicated that the experimental maize had been infected by both field and storage fungi. The rate of kernel infection by storage fungi, in percent infected kernels, was higher than the rate of infection by field fungi (Table 5.1).

TABLE 5.1. INCIDENCE OF FIELD AND STORAGE FUNGI ON INITIAL MAIZE SAMPLE.

Fungi	Percentage of kernels yielding fungi
Alternatia sp.	1
Cladosporium sp.	32
Nigrospora sp.	3
Rhizopus sp.	87
Absidia sp.	76
Aspergillus sp.	8
Penicillium sp.	99

The presence of both field and storage fungi on the initial grain sample was an indication that the grain might be fresh but might have been held temporarily in country elevators or blended, at a terminal elevator, with an older grain. This phenomenon of primary innoculum had been demonstrated by Tuite and Christensen (1957). By the end of the twelfth week of storage, no field fungus was observed on the maize kernels that were examined. The major storage fungi, Penicillium species and Aspergillus species, predominated by the middle of the storage period and thereafter (Table 5.2).

Table 5.2 INCIDENCE OF FUNGI ON MAIZE SAMPLES TAKEN FROM THE PLYWOOD AND CONCRETE BINS ON THE 12TH AND 24TH WEEK OF STORAGE. (24TH WEEK FIGURES ARE IN PARENTHESIS).

Fungi	Percent Maize Kernels Infected					
	P1	P2	P3	C1	C2	C3
Penicillium sp.	98	100	100	100	100	100
	(100)	(100)	(100)	(100)	(100)	(100)
Aspergillus sp.	82	76	37	69	75	73
	(100)	(97)	(100)	(98)	(98)	(99)
Absidia sp.	64	74	89	53	25	43
	(28)	(10)	(5)	(8)	(12)	(12)
Rhizopus sp.	25	11	48	15	12	44
	(11)	(29)	(21)	(8)	(12)	(30)
Cladosporium sp.	---	---	---	---	---	---
	(5)	(15)	(6)	(17)	(3)	(7)
Trichoderma sp.	---	---	---	---	---	---
	(5)	(17)	(---)	(5)	(---)	(5)
Chaetomium sp.	---	---	---	2	6	---
	(2)	(---)	(---)	(---)	(---)	(7)

In addition to these two storage fungi, there were also Absidia sp., Rhizopus sp. and Cladosporium sp. The presence of Cladosporium sp. was quite unexpected as this genus has been classified as a field fungus rather than as a storage type. The incidence of this fungus might be explained by considering its characteristics. Generally, members of this genus are saprophytic on plant material and some species are noticeable on fresh decaying plant material (Barnett, 1956). The absence of Cladosporium sp. on the maize kernels at the end of 12 weeks of storage and its appearance by the end of the storage period (24 weeks) was an indication of the onset of decay in the grain bulk and also in plant materials (foreign matter) present in the grain bulk. The other fungus revealed by the analysis, but in very small proportions, was the genus Trichoderma. Members of this group of fungus are hyper-parasitic on various fungi.

5.1.5 Grain Viability

At the beginning of the storage experiment, the maize had a rather low germination capacity of 45%. At the end of the experiment the germination capacity had dropped to zero percent. None of the seeds showed any ability to germinate. For a comparison, seeds obtained from the original sample and kept at room temperature in a metal can germinated. The kernels might have been killed completely by ~~the~~ rather high fungal infection rate. Moreno et al (1965) had demonstrated that uninoculated maize (which was free from storage fungi) stored at 17% m.c. and at 25°C retained a germination capacity of 98% after twelve weeks, whereas only 6% germinated when inoculated with storage fungi and stored under identical conditions.

5.2 Physical Parameters

5.2.1 Grain Temperature

The experimental grain went into the storage bins at a rather low temperature of about 7°C. By the end of the second week of storage and under an average ambient temperature of about 23°C, the grain bulk temperatures started to vary from one point to the other. During the second week of storage, that is, the first week of grain temperature recording, the range of temperature differences between points inside the grain bulk was very small. For convenience and simplicity temperature variations within and between bins are given here on a weekly mean basis rather than on a daily basis even though temperatures were recorded daily during the experiment. In certain specific situations, such as in the development of hot spots, grain temperatures are given on a daily basis.

Generally, all the bins showed a remarkable increase in grain bulk temperatures between the third and fourth weeks of storage. Increases in grain temperatures at various points within the plywood bins were initially very small and all temperatures were below the ambient temperature (Figures 5.3a, 5.4a and 5.5a). Temperatures then started showing sharp increases during the fourth week and, by the end of the sixth week of storage, temperatures at all three levels in all three plywood bins were above the ambient temperature and remained so throughout the remainder of the storage period as shown in Figures 5.3b, 5.4b and 5.5b.

Initially, there were variations in the temperatures between levels for all the plywood bins as illustrated in Figures 5.3a, 5.4a and 5.5a. The warmest level, for example, in plywood bin 2, was the middle level at the fourth week. Temperature differences between the levels were still very small. The upper, middle and lower and ambient mean temperatures were 35°C, 36.2°C, 35.2°C and 25.2°C, respectively. Between the sixth and thirteenth week, there were remarkable variations in temperatures in the upper, middle and lower levels in all plywood bins. On the whole, the warmest and coolest level were the middle and the lower levels respectively with the upper level occupying an

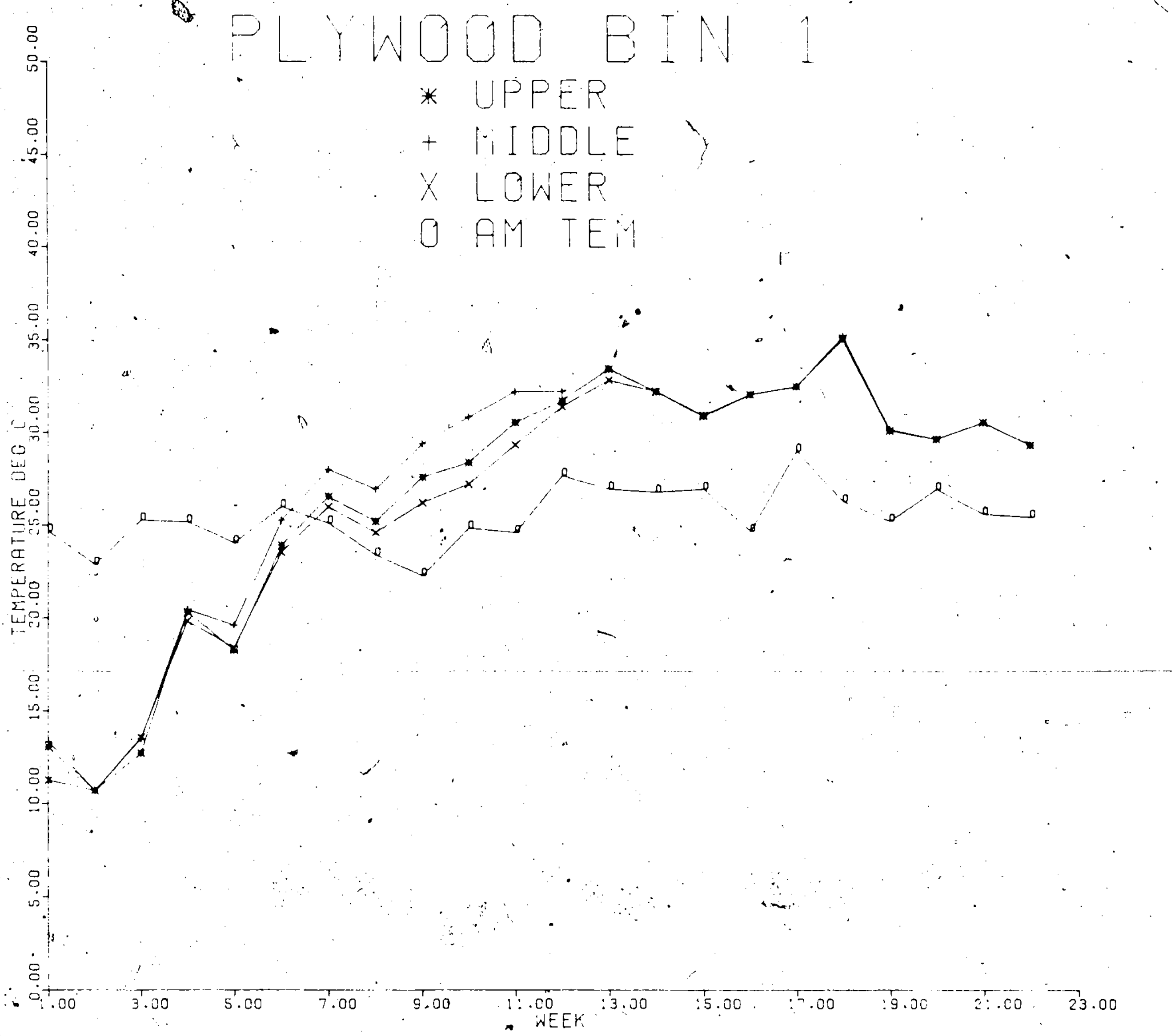


Figure 5.3a: Relationship between the weekly mear temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 1.

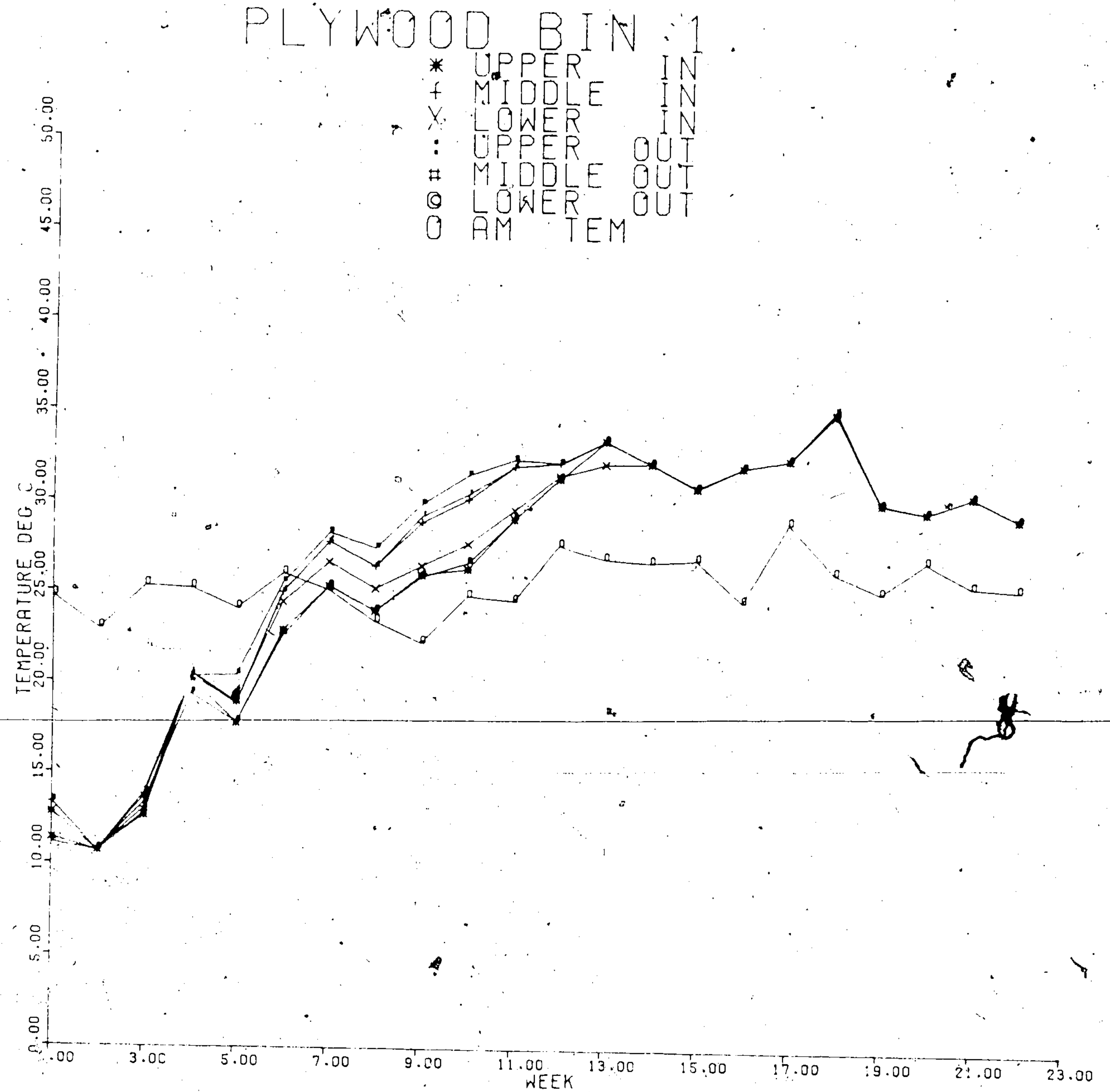


Figure 5.3b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 1.

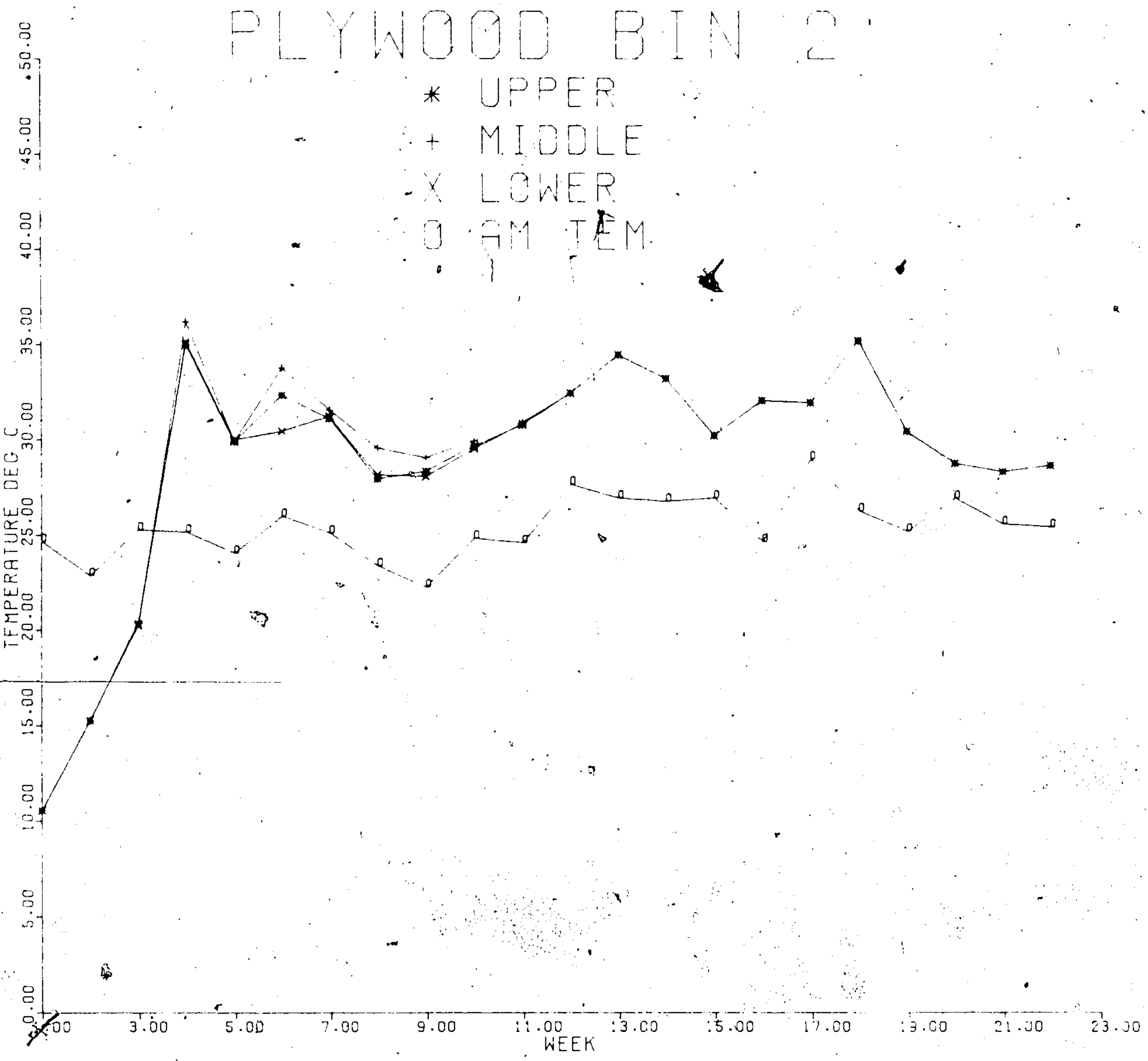


Figure 5.4a: Relationship between the weekly mean temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 2.

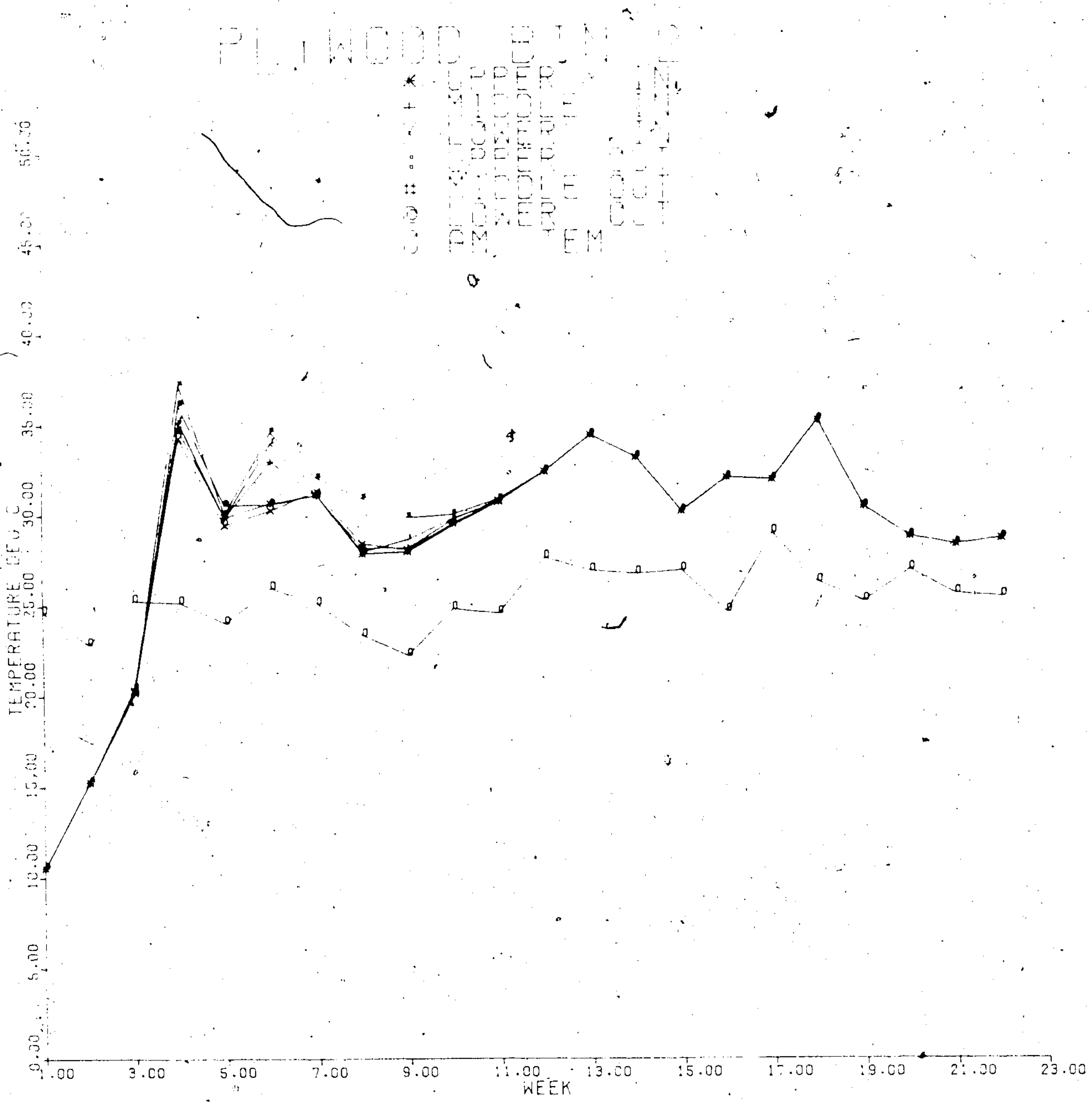


Figure 5.4b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 2.

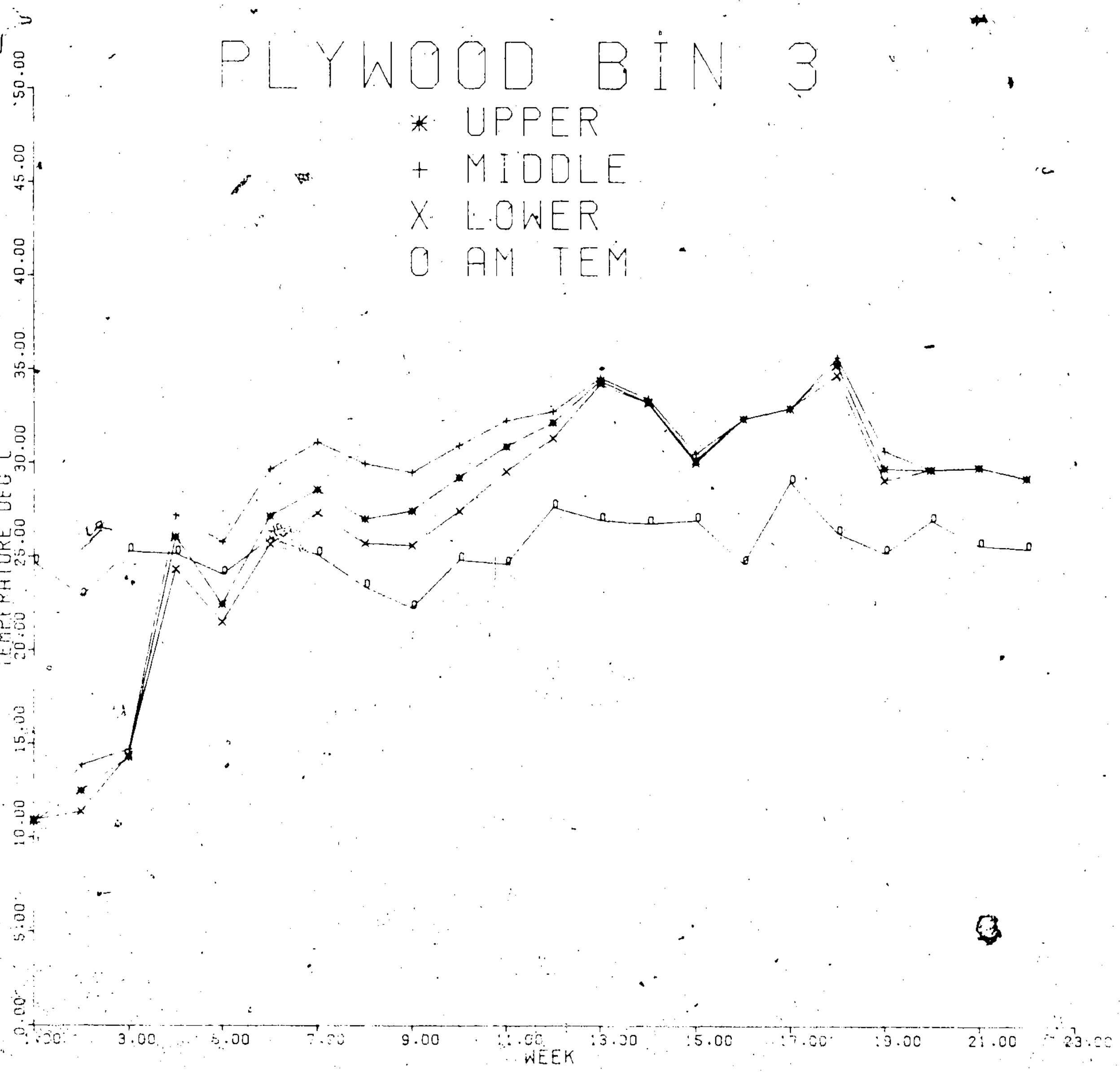


Figure 5.5a: Relationship between the weekly mean temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 3.

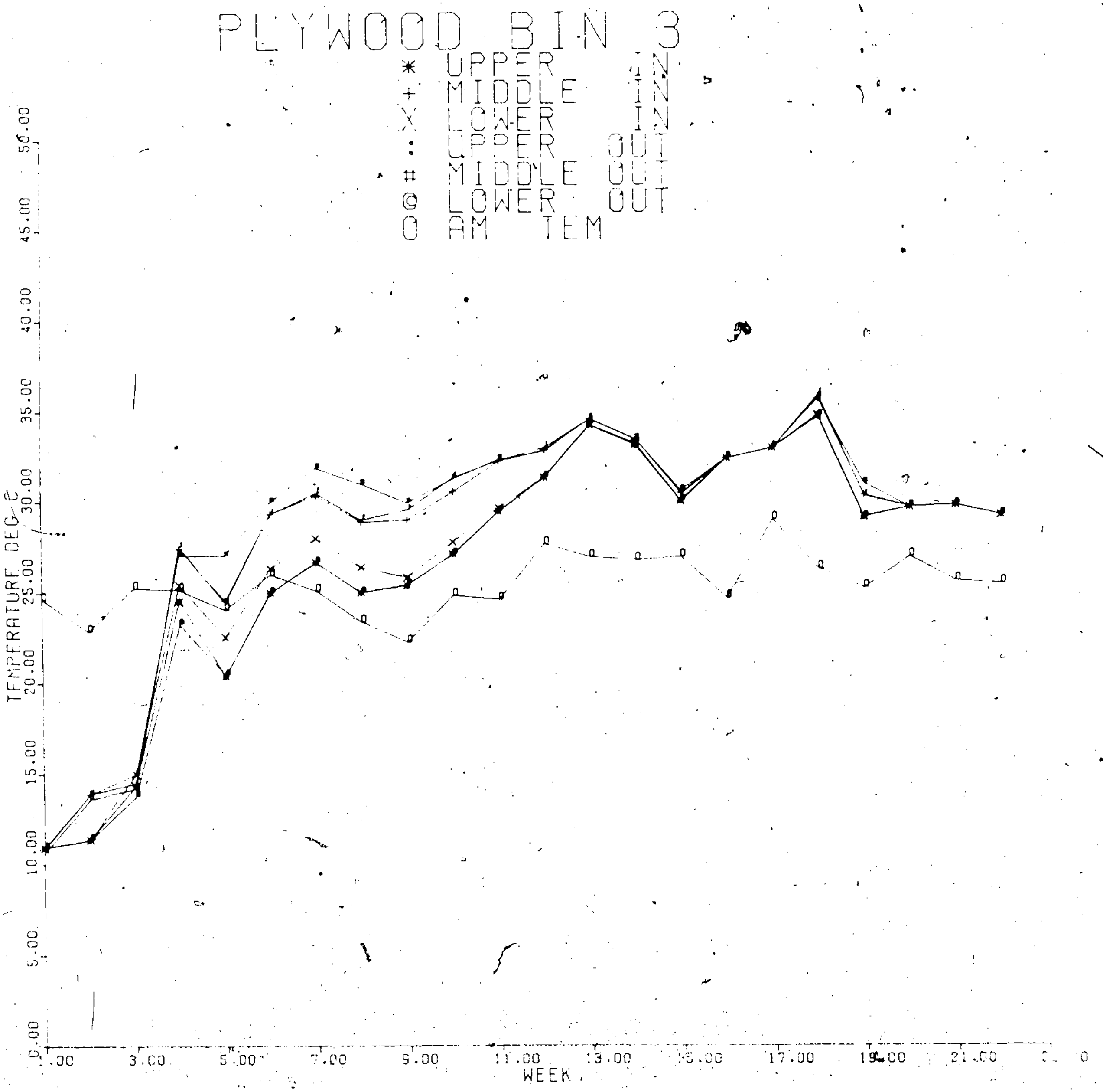


Figure 5.5b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in plywood bin 3.

intermediate position. Generally, the average temperature differences between the warmest and coolest levels ranged between 3.4°C to 4.3°C for the plywood bins.

A further analysis of the temperatures for each of the three levels indicated [illegible] the warmest area or region within the grain bulk was the outer circ[illegible] (as marked by the thermocouple locations) in the middle level, that is, the peripheral regions as indicated in Figures 5.3b, 5.4b and 5.5b. The coolest regions were in the inner and outer circles of the upper and lower levels respectively. Maximum temperature differences in the warm and cool regions ranged between 4.3°C to 6.7°C. The mean maximum temperature of the grain mass in plywood bins was 35.3°C.

There were a few hot spots created, especially in plywood bin 2. These hot spots were noticed on the twenty-sixth day, that is, during the fourth week, at thermocouple points 13 to 16 and 21 to 24, and again on the thirty-fifth day (end of fith week) at points 5 to 8 and 13 to 16. Temperatures at these hot spots were about 42.2°C and persisted for only the day specified. This could mean that the heat generated was dissipated rapidly through the grain bulk.

The situation within the concrete bins was quite different from what was observed in the plywood bins. The rise in temperature inside the grain mass was initially very gradual. The rate increased very rapidly after the third week and, by the end of the sixth week, the grain bulk temperatures were above most of the ambient (Figures 5.6 to 5.8). An interesting phenomenon observed in all the concrete bins was that there were no variations in temperature between the monitored points inside the grain bulk, that is, at any particular time during the period of the experiment, grain bulk temperatures were

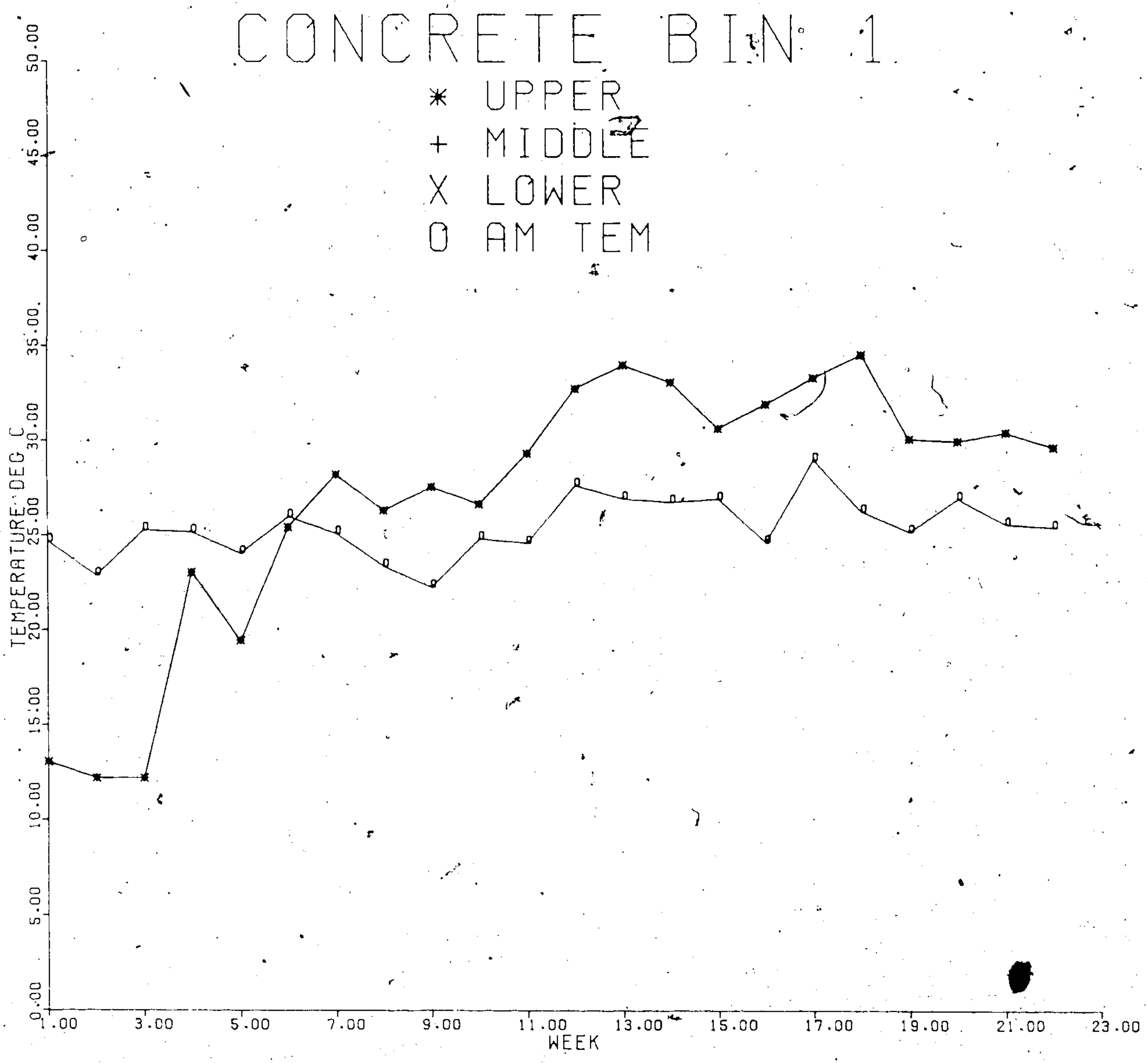


Figure 5.6a: Relationship between the weekly mean temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in concrete bin 1.

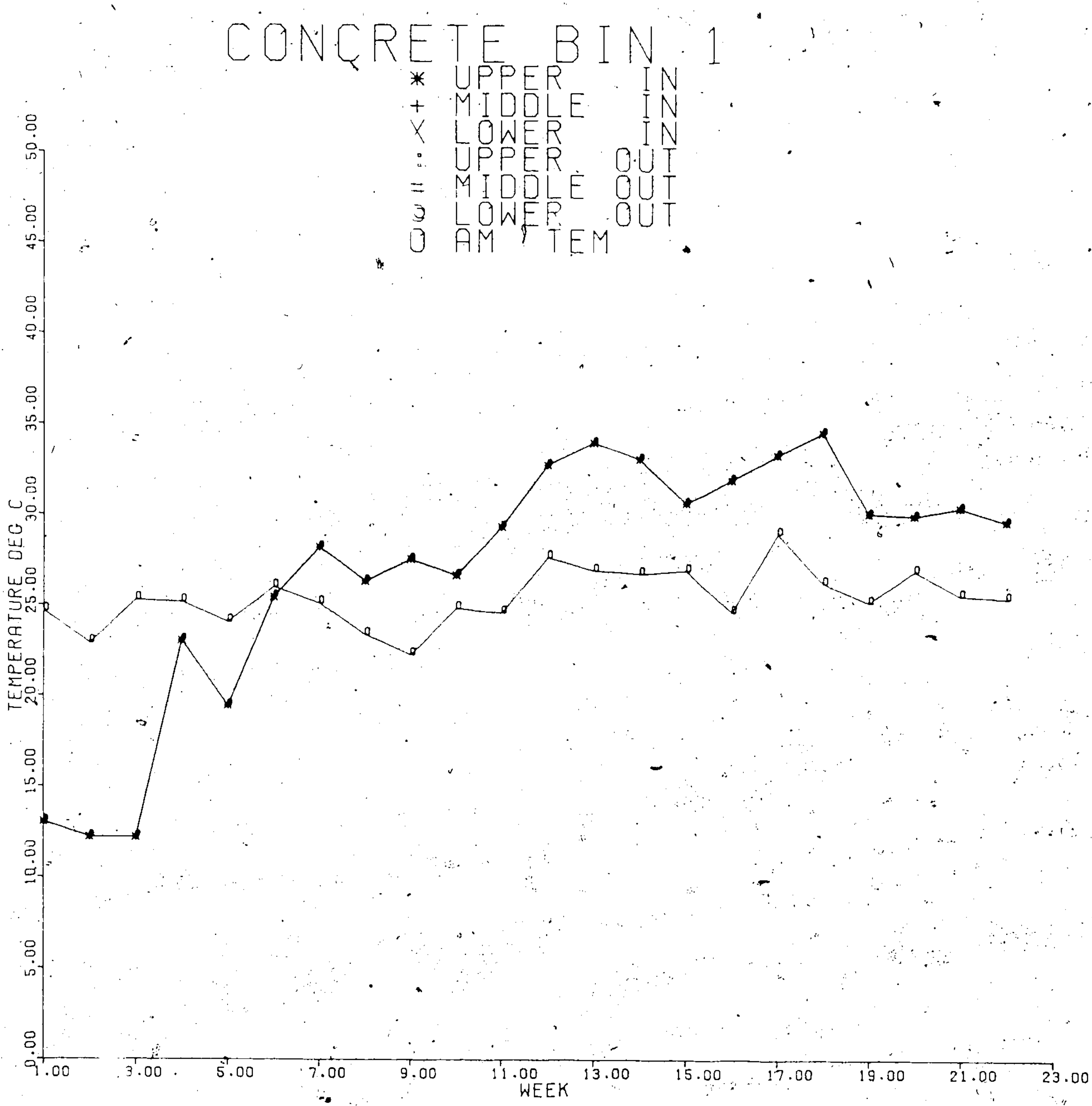


Figure 5.6b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize ~~in~~ concrete bin 1.

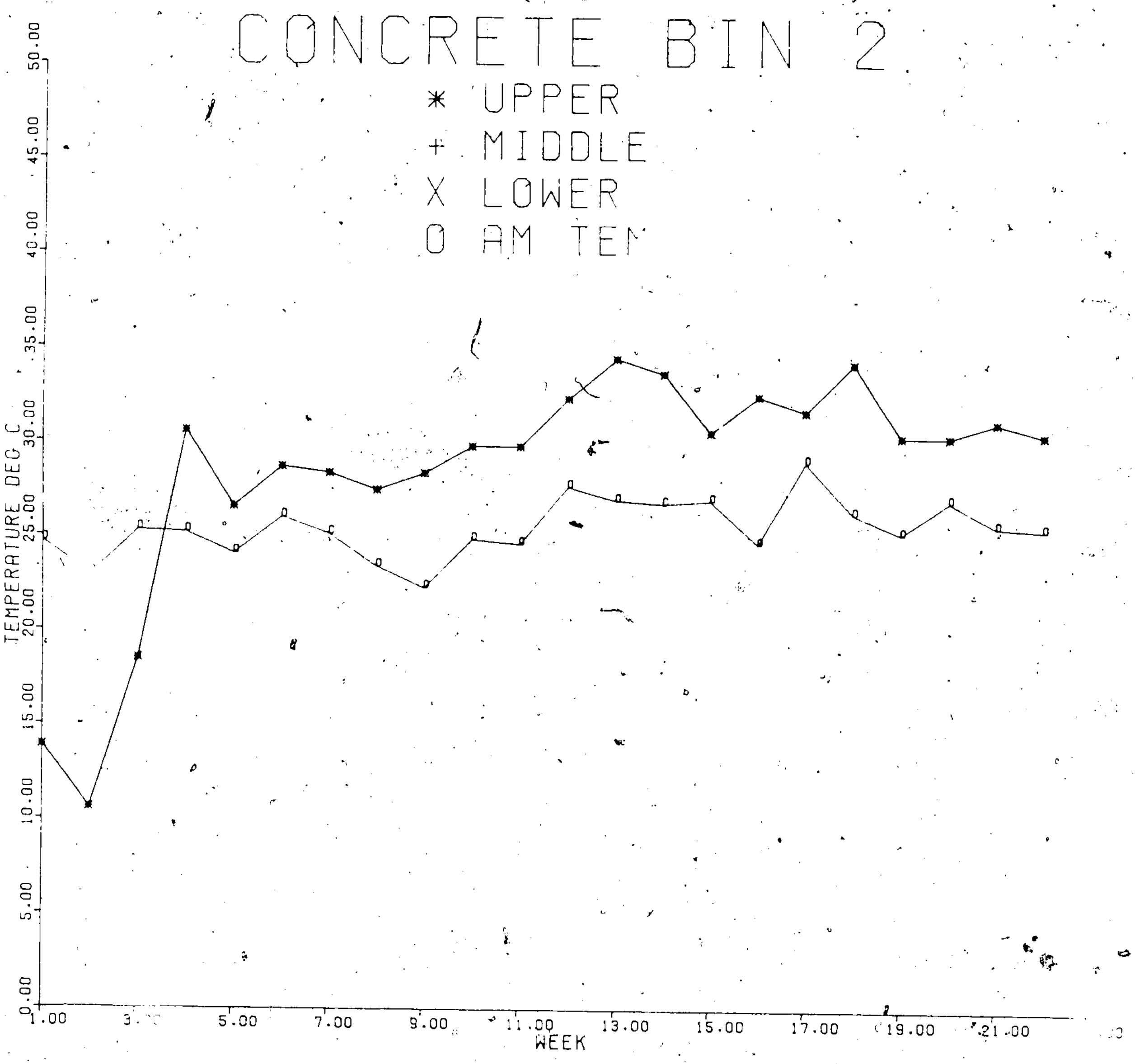


Figure 5.7a: Relationship between the weekly mean temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in concrete bin 2.

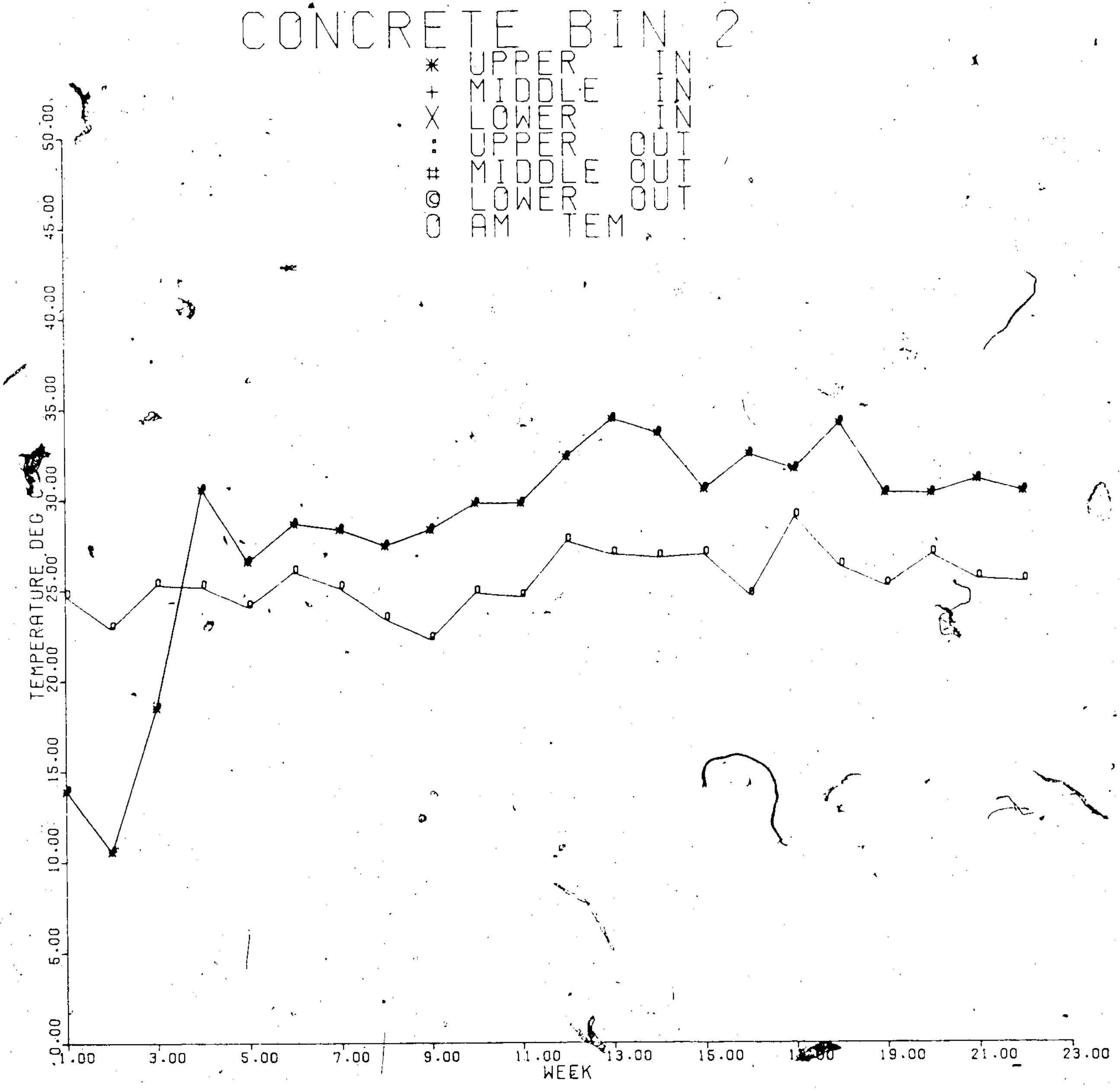


Figure 5.7b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in concrete bin 2.

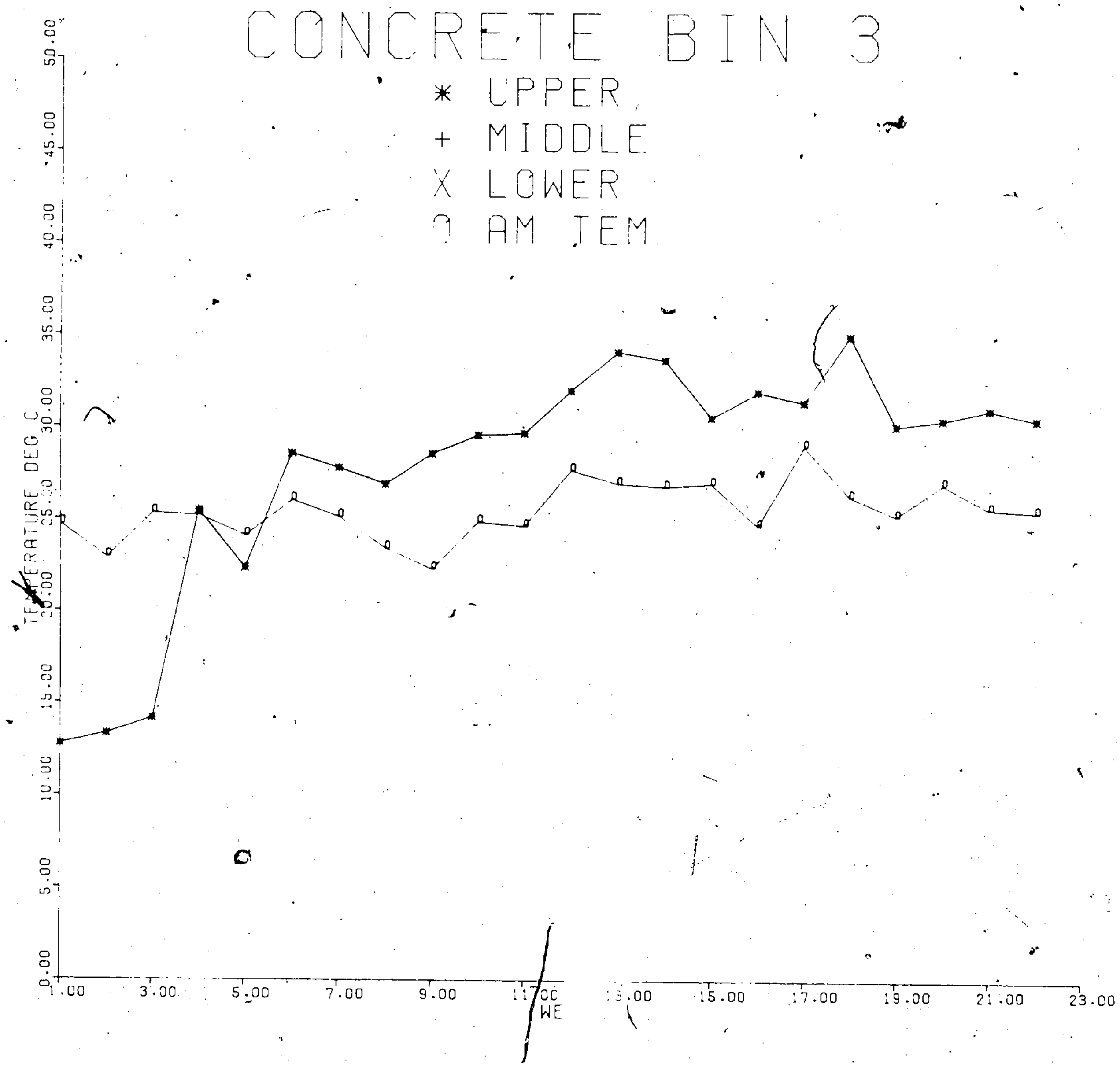


Figure 5.8a: Relationship between the weekly mean temperatures at three levels within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in concrete bin 3.

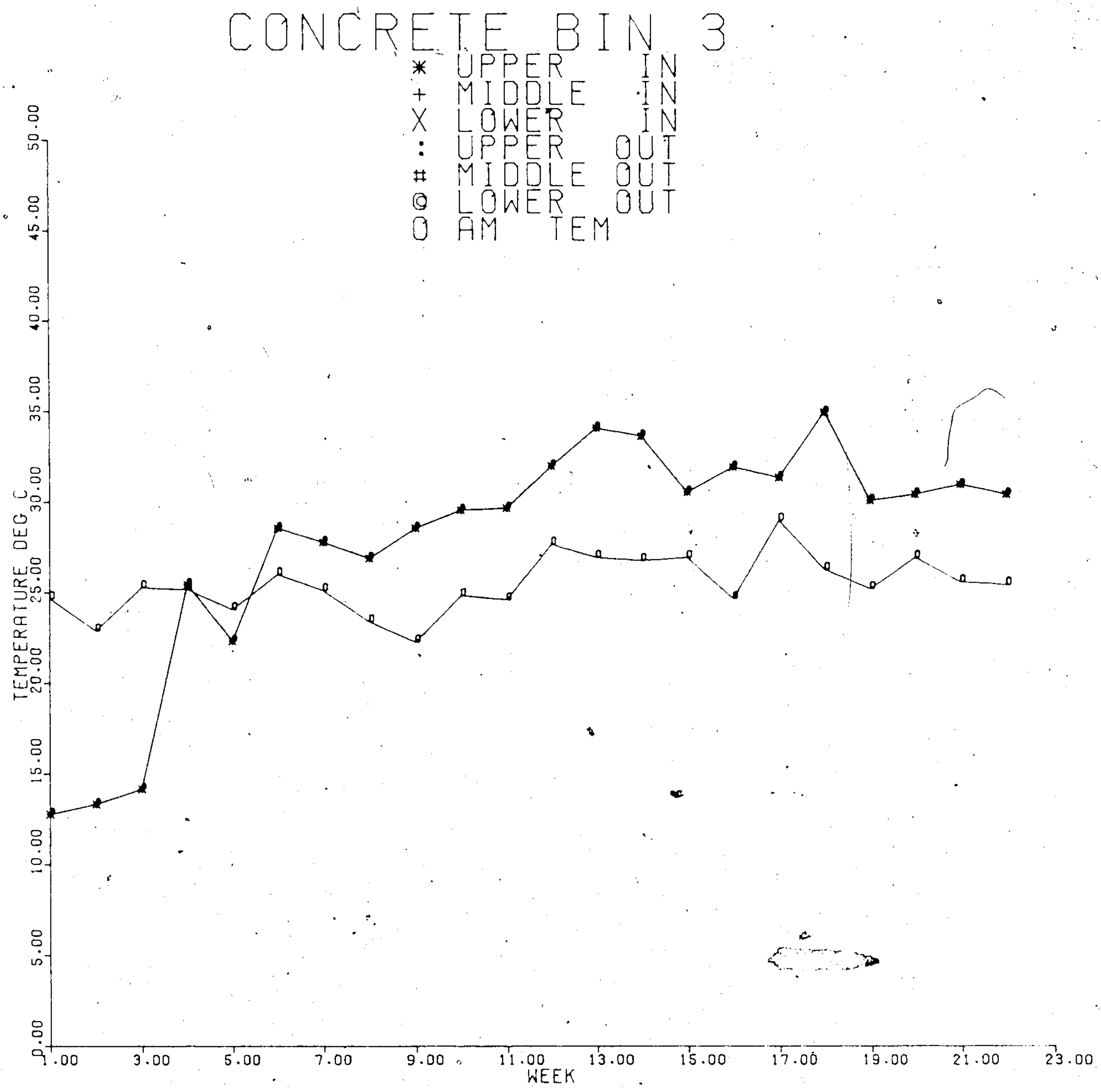


Figure 5.8b: Relationship between the weekly mean temperatures at the two radial spacings (of thermocouples) on each level within the grain bulk and the weekly mean ambient temperatures (AM TEM) during storage of maize in concrete bin 3.

uniform throughout the bin and the only variation in temperature that occurred was a function of time in storage. This situation occurred also in the plywood bins but only in the later stages of the storage period as shown in Figures 5.3 to 5.5.

In all bins, temperature variations within the grain bulk followed the trend in the ambient temperature variations with a time lag of about one week (Figures 5.3 to 5.8). Thus, the rise or fall in ambient temperature produced a corresponding rise or fall in grain bulk temperatures but with a time delay of about one week.

5.2.1.1 Analysis of Variance - Grain Temperature

The analysis of variance calculations for all data were made using a computerized programme (Weingardt, 1975) at the University of Alberta Computing Centre. The title of this programme is *ANOFPR which uses the Fortran IV language in the calculation of analysis of variance. The F-values and consequently the probability levels are calculated for specified main effects and their interactions. For purposes of simplicity and concise interpretation of results of the analysis of variance, weekly data rather than daily data have been used. The temperature means for weeks, radial and vertical spacings for each of six bins are presented in Appendix II. The analysis of variance results for the temperatures within the bins and for temperatures within the grain bulk and ambient temperature are given in Tables 5.3 and 5.4 respectively.

Results of the statistical analysis (Table 5.3) indicated that significant differences existed for the main effects of radial spacing (position), vertical spacing (level) and weeks of storage. This is an indication that the variation of temperatures between weeks

TABLE 5.3: ANALYSIS OF VARIANCE RESULTS FOR MEAN TEMPERATURES WITHIN THE BINS.

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARES	F-VALUE	PROBABILITY
Material (M)	1	1.20	0.0098	0.9257
B/M (Bin/M)	4	121.72		
Position (P)	1	6.40	14.81	0.0183*
PM	1	6.40	14.82	0.0183*
PB/M	4	1.73	0.43	
Level (L)	2	17.07	6.98	0.0176*
LM	2	17.07	6.98	0.0176*
LB/M	8	2.45		
PL	2	6.08	3.83	0.0683
PLM	2	6.08	3.83	0.0683
PLB/M	8	1.59		
Week (W)	21	1474.30	69.76	0.0000***
WM	21	6.45	0.31	0.9984
WB/M	84	21.13		
WP	21	0.39	3.43	0.0000***
WPM	21	0.39	3.43	0.0000***
WPB/M	84	0.11		
WL	42	0.90	4.19	0.0000***
WLM	42	0.90	4.19	0.0000***
WLB/M	168	0.21		
WLP	42	0.42	3.31	0.0000***
WLPM	42	0.42	3.31	0.0000***
WLPB/M	168	0.13		
TOTAL	791			

* Significant at .05 probability level
** Significant at .01 probability level
*** Significant at .001 probability level

or, for that matter, between days, over the entire storage period, between the radial spacings, and between the vertical spacings were statistically significant. The differences in the above three main effects occurred in all the plywood bins. The concrete bins did not show any differences in temperatures for the radial and vertical spacings but showed significant differences in the weekly variations of temperature in the entire grain bulk. There was, however, no significant difference between the two materials, that is, the plywood and the concrete. The variation of temperatures within both the plywood and concrete bins was very high as shown by a high mean square value in Table 5.3 and Figure 5.19.

TABLE 5.4: ANALYSIS OF VARIANCE RESULTS FOR THE WEEKLY MEANS OF GRAIN AND AMBIENT TEMPERATURES.

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARES	F-VALUE	PROBABILITY
Material (M)	1	0.10	0.01	0.925
B/M (Bin/M)	4	10.08		
Week (W)	21	161.05	91.69	0.000***
WM	21	0.53	0.30	0.999
WB/M	84	1.76		
Temperature (T)	1	345.93	34.30	0.004**
TM	1	0.10	0.01	0.925
TB/M	4	10.08		
WT	21	99.23	56.50	0.000***
WTM	21	0.53	0.30	0.999
WTB/M	84	1.76		
TOTAL	263			

* Significant at .05 probability level
** Significant at .01 probability level
*** Significant at .001 probability level

5.2.2 Grain Moisture

At the beginning of the experiment, a moisture analysis of the initial samples taken at the time of filling the bins indicated a moisture content range of 15.38 to 15.74 percent wet basis. The average was 15.62 percent. The range recorded for plywood bin 1 on refilling was from 15.42 to 15.54 percent with an average of 15.48 percent. The maximum difference, therefore, in the moisture content of grain at various points within plywood bins 2 and 3, and all three concrete bins was 0.36 percent. Similary for plywood bin 1, the corresponding difference was 0.12 percent.

The moisture content results for the samples taken at the

12th and 24th week of storage are presented in Appendices IV and V. In general, the grain in the three plywood bins had decreased in moisture content by the middle of the storage experiment. The extent of this decrease varied from one point to another among the 26 points from which the samples were taken. There were a few relatively high moisture pockets inside bins 2 and 3. These pockets were localized in the middle and lower levels. Very high moisture areas developed in the outer circle of the thermocouple arrangement in the upper level in all the plywood bins. The levels on the whole showed a decrease in moisture content as shown in Figures 5.9a, b and c. At the end of the experiment, all three levels within the plywood bins had decreased in moisture content to about 14 percent. The driest area in each of the plywood bins was the top centre of the grain. This area decreased 2.51 percentage points from 15.62 to 13.11 percent over the 24 weeks of storage.

The vertical and horizontal arrangements of the thermocouple points produced two concentric cylinders. The inner and outer cylinders were designated as the inner and outer cores respectively. Both cores showed decreases in grain moisture in all plywood bins. The inner cores, however, were drier than the outer cores (Figures 5.10a, b and c).

Maize in the concrete bins behaved differently from that in the plywood bins in terms of moisture distribution within the grain bulk. Grain moisture analysis at the end of 24 weeks of storage showed only a few points that had appreciable decreases in moisture. Most of the points within the grain bulk maintained moisture levels that were higher than 15.0%. The areas with the highest moisture content were the peripheral areas on top of the grain. In all three concrete bins, these areas increased in moisture up to above 18%. Spots or areas of

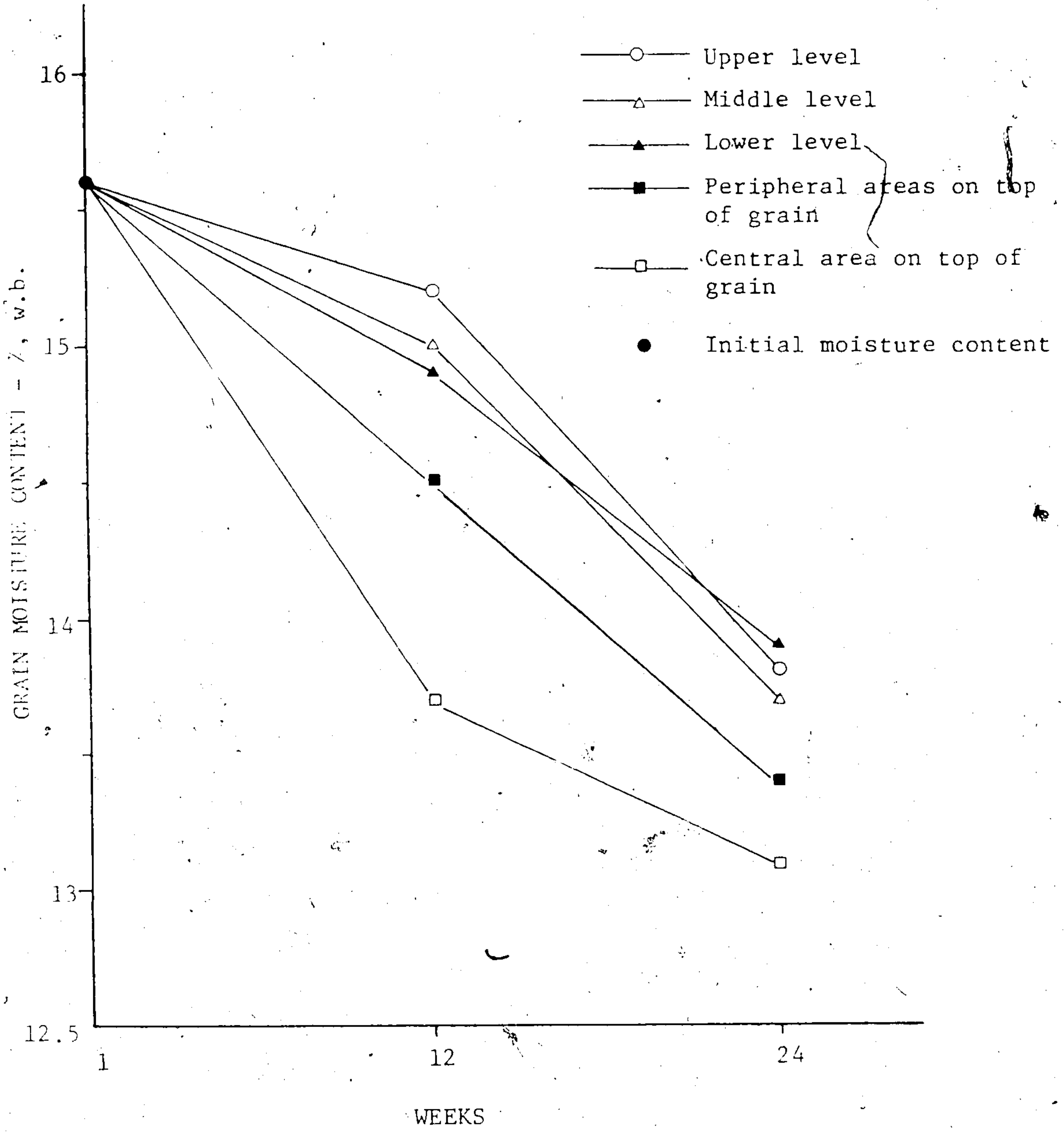


FIGURE 5.9a: Grain moisture content variations at the various levels within plywood bin 1 during storage.

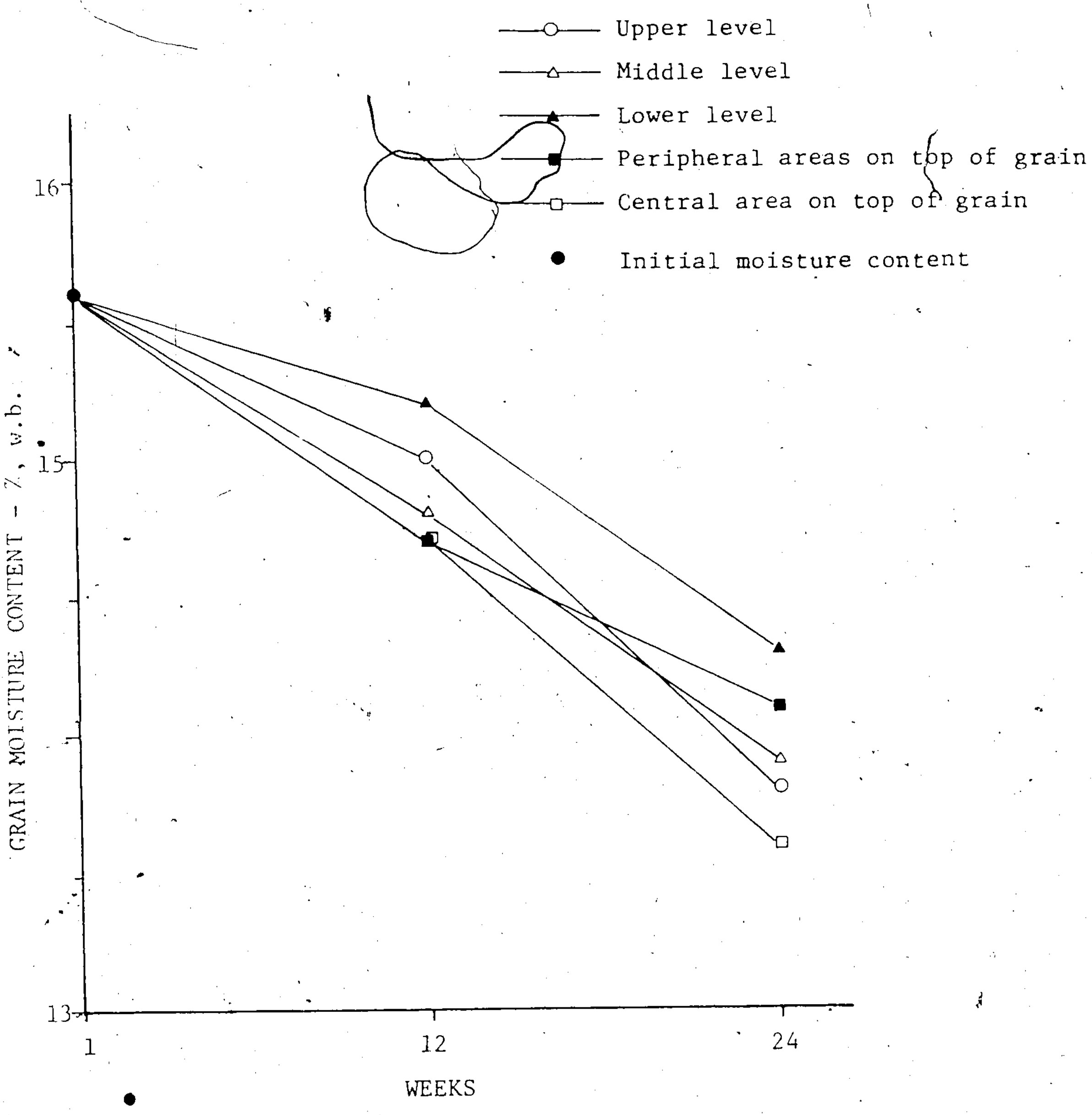


FIGURE 5.9b: Grain moisture content variations at the various levels within plywood bin 2 during storage.

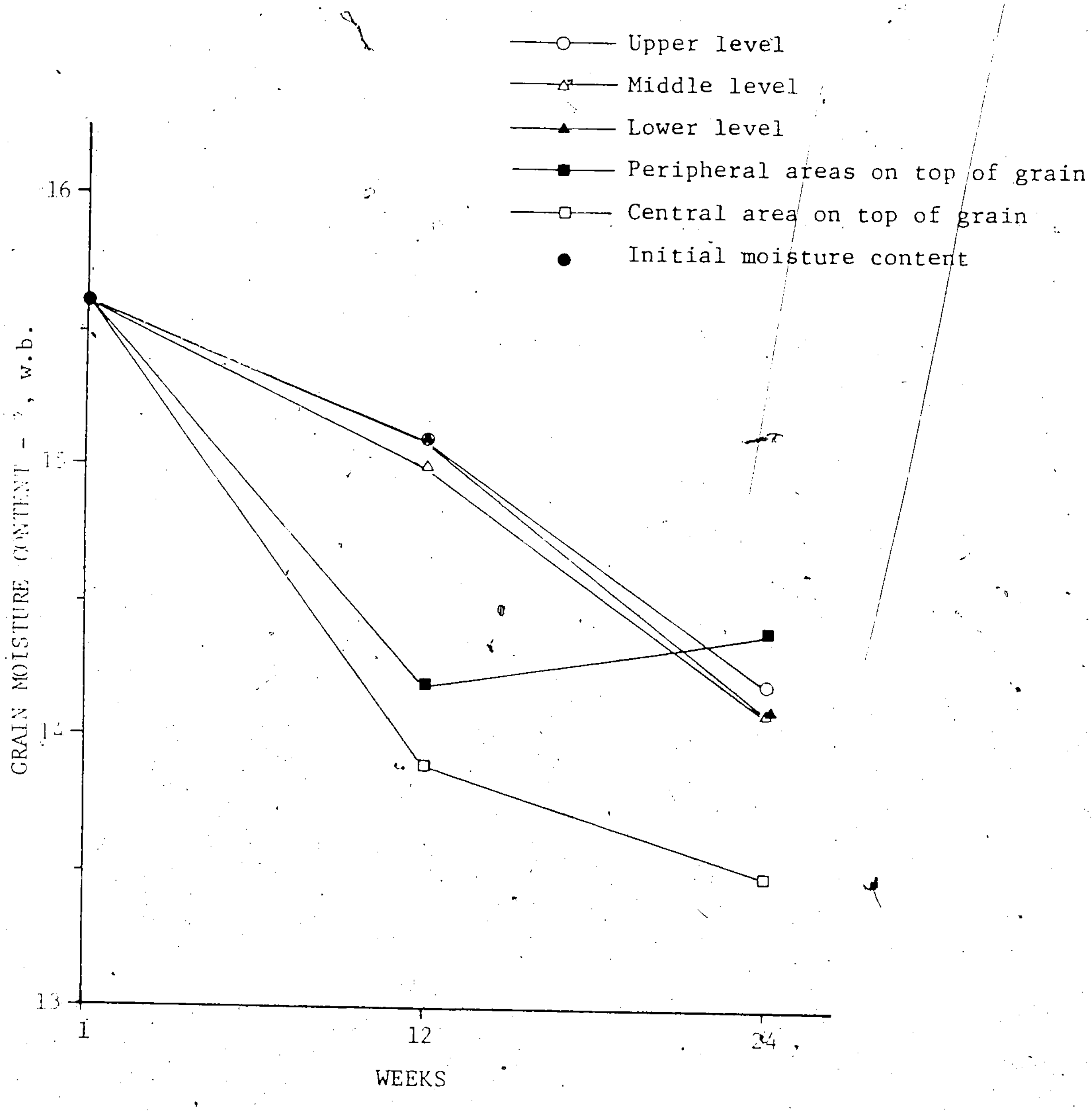


FIGURE 5.9c: Grain moisture content variations at the various levels within plywood bin 3 during storage.

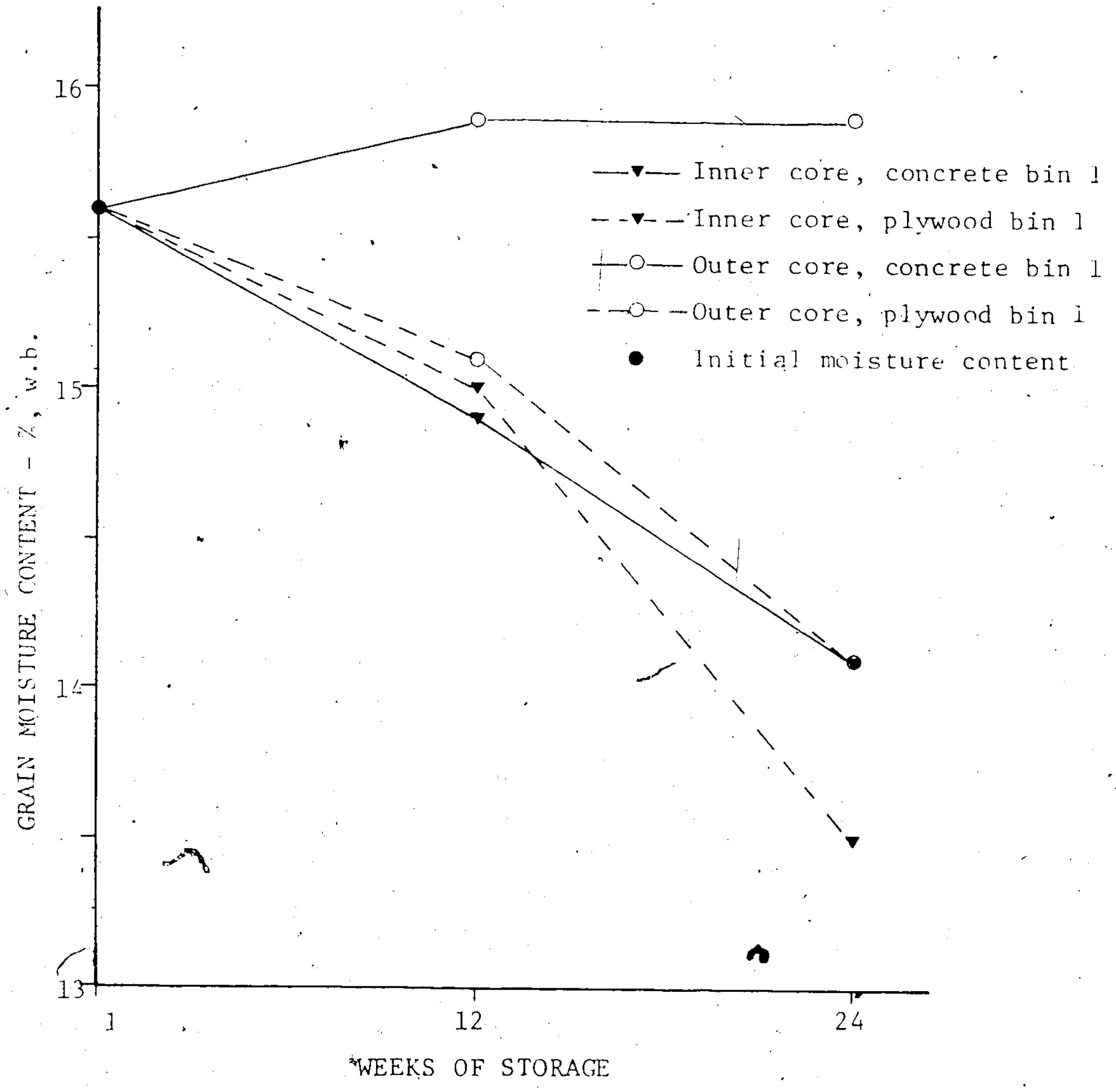


FIGURE 5.10a: Grain moisture content variations at various areas within the grain bulk during storage in concrete bin 1 and in plywood bin 1.

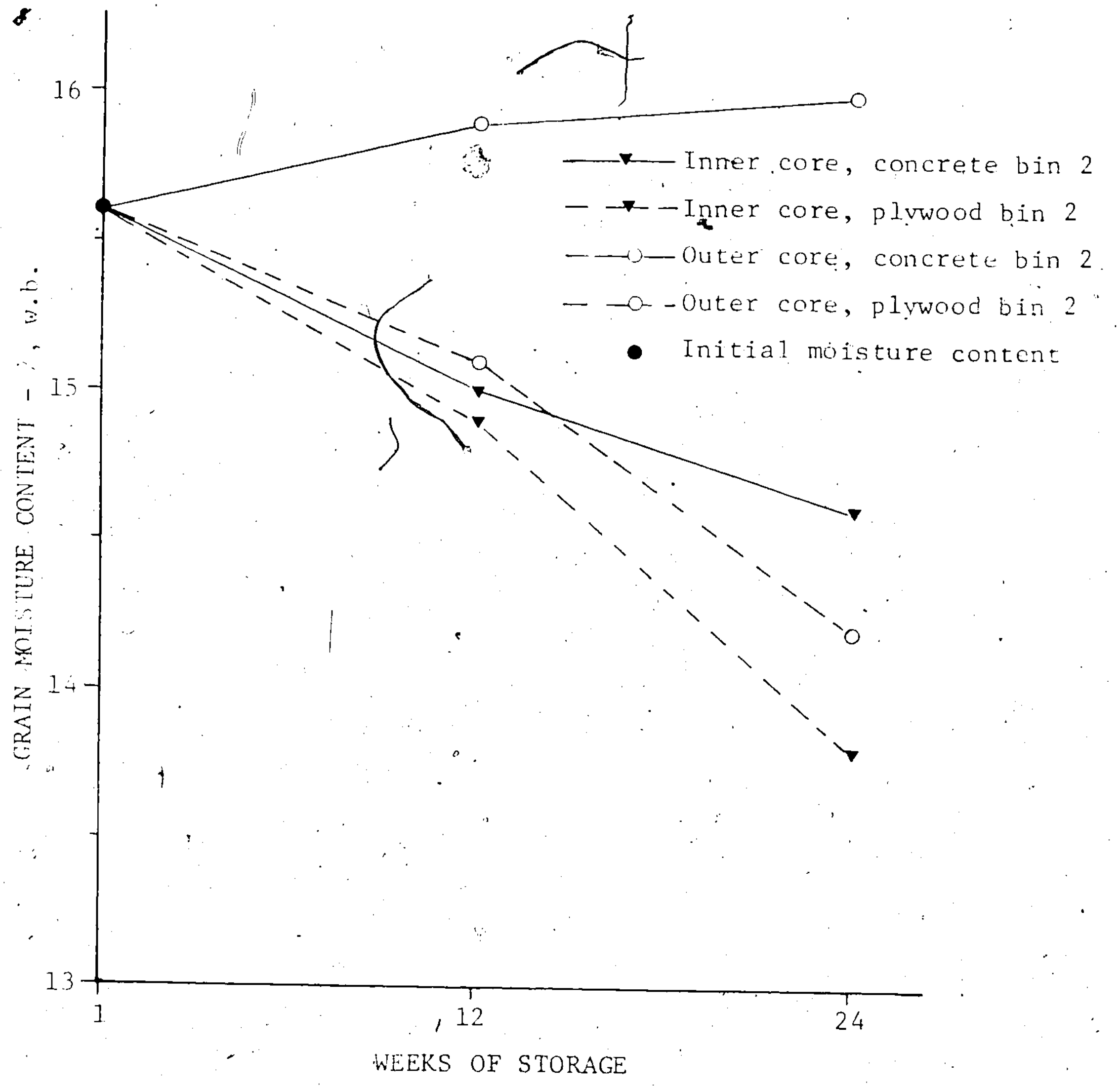


FIGURE 5.10b: Grain moisture content variations at various areas within the grain bulk during storage in concrete bin 2 and in plywood bin 2.

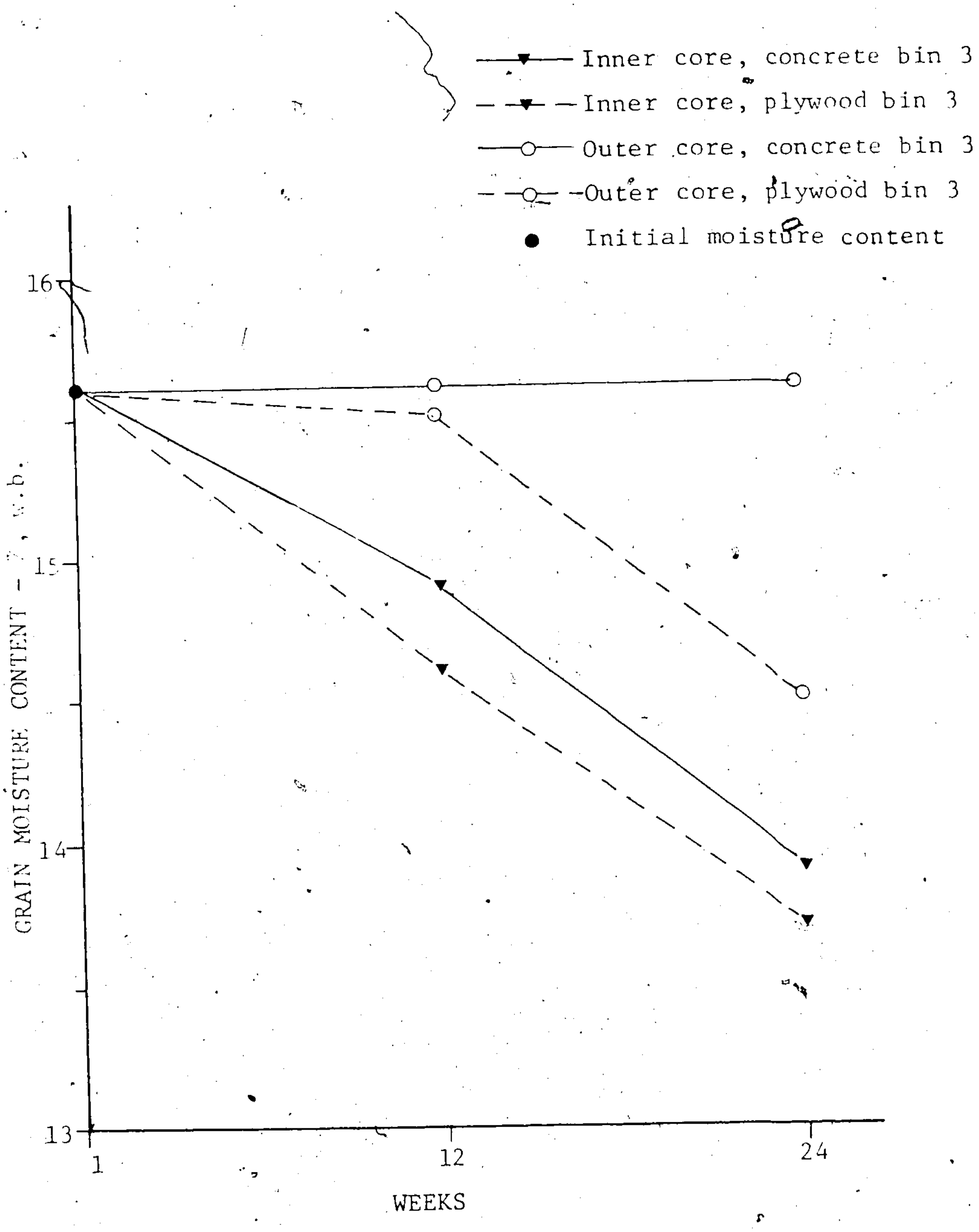


FIGURE 5.10c: Grain moisture content variations at various areas within the grain bulk during storage in concrete bin 3 and in plywood bin 3.

reduced moisture content were localized mainly in the central part of the grain mass in all three bins.

The upper and middle levels within the grain bulk in the concrete bins showed decreases in moisture content at the end of the 24 weeks of storage. The lower levels, however, increased slightly in moisture content, as illustrated in Figures 5.11a, b and c, with the moisture level going up and beyond the initial moisture value of 15.6%. The peripheral areas again registered high moisture levels that exceeded 19.0% in all three bins. At the end of the experiment; the moisture level of the grain in the peripheral area in bin 2 reached a value above 22% (Figure 5.11b).

The outer cores in the concrete bins also had more moisture than the inner cores. This indicated that there was 'wetting' in the outer core and 'drying' in the inner core as shown in Figures 5.12a and b, and 5.13a and b.

The increase or decrease in moisture content or, in other words, the redistribution of moisture within the grain bulk exhibited a particular trend or flow in both the plywood and concrete bins. This flow pattern suggested that, for any of the defined planes, either north-south or east-west, and at any point on a defined level (upper, middle or lower) the movement of moisture was two dimensional. Taking a reference point on the central vertical axis of a defined plane and on a given level or layer, the movement of moisture inside the grain bulk was both downwards and laterally (Figures 5.14 and 5.15), that is, moisture moved away from the centre and towards the peripheral areas and the floor in all the bins without regard to the constructional material used.

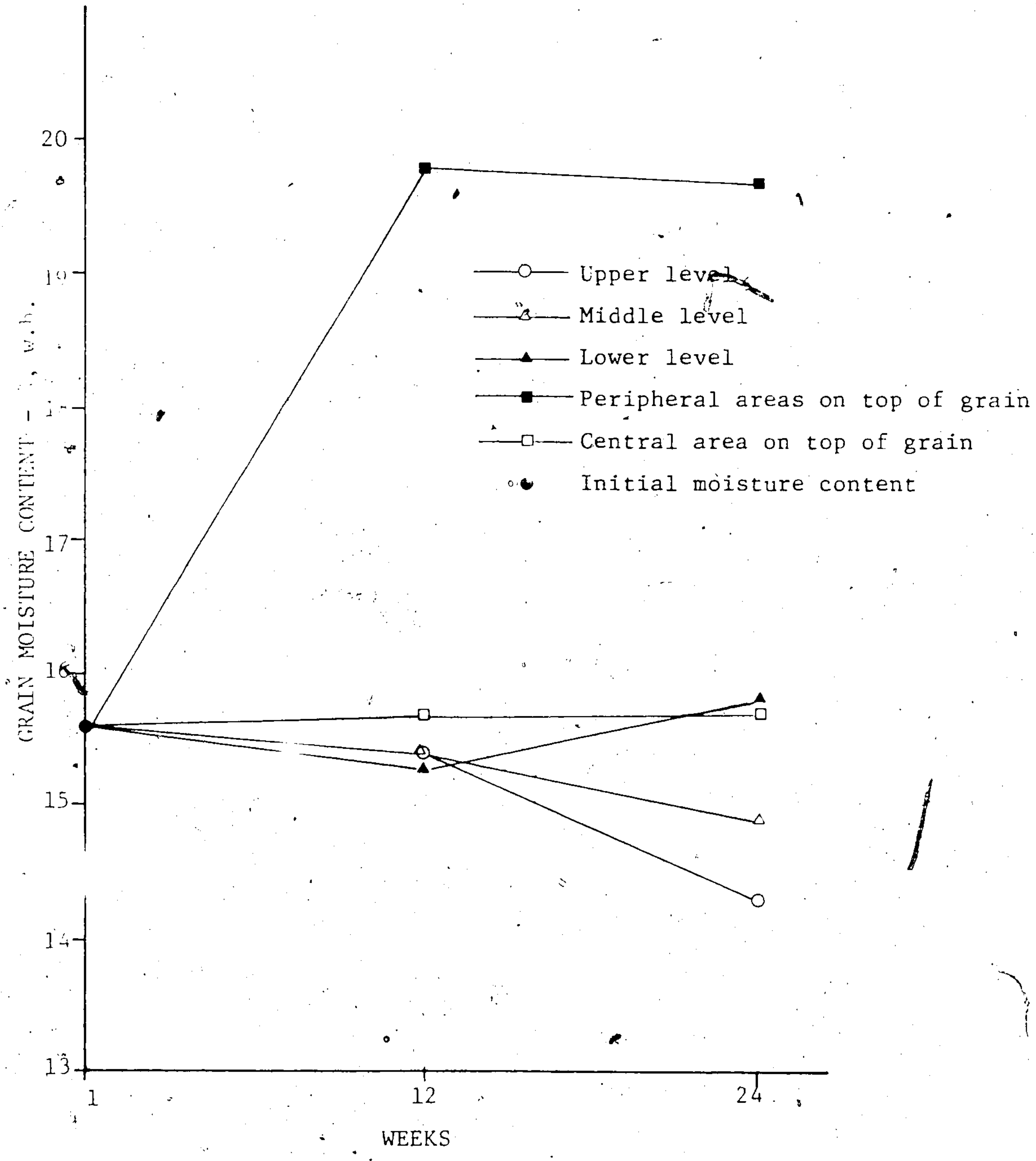


FIGURE 5.11a: Grain moisture content variations at the various levels within the grain bulk during storage in concrete bin 1.

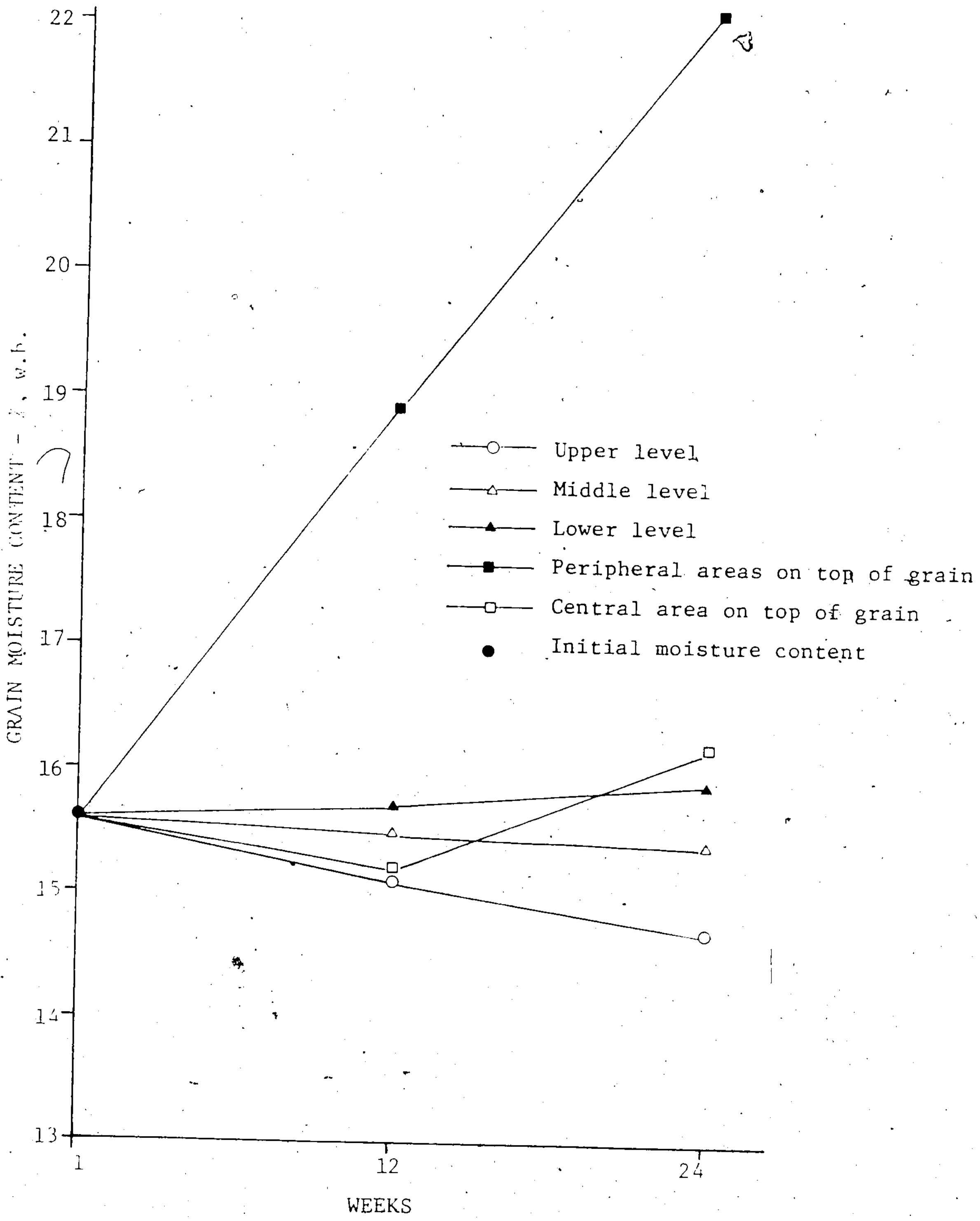


FIGURE 5.11b: Grain moisture content variations at the various levels within the grain bulk during storage in concrete bin 2.

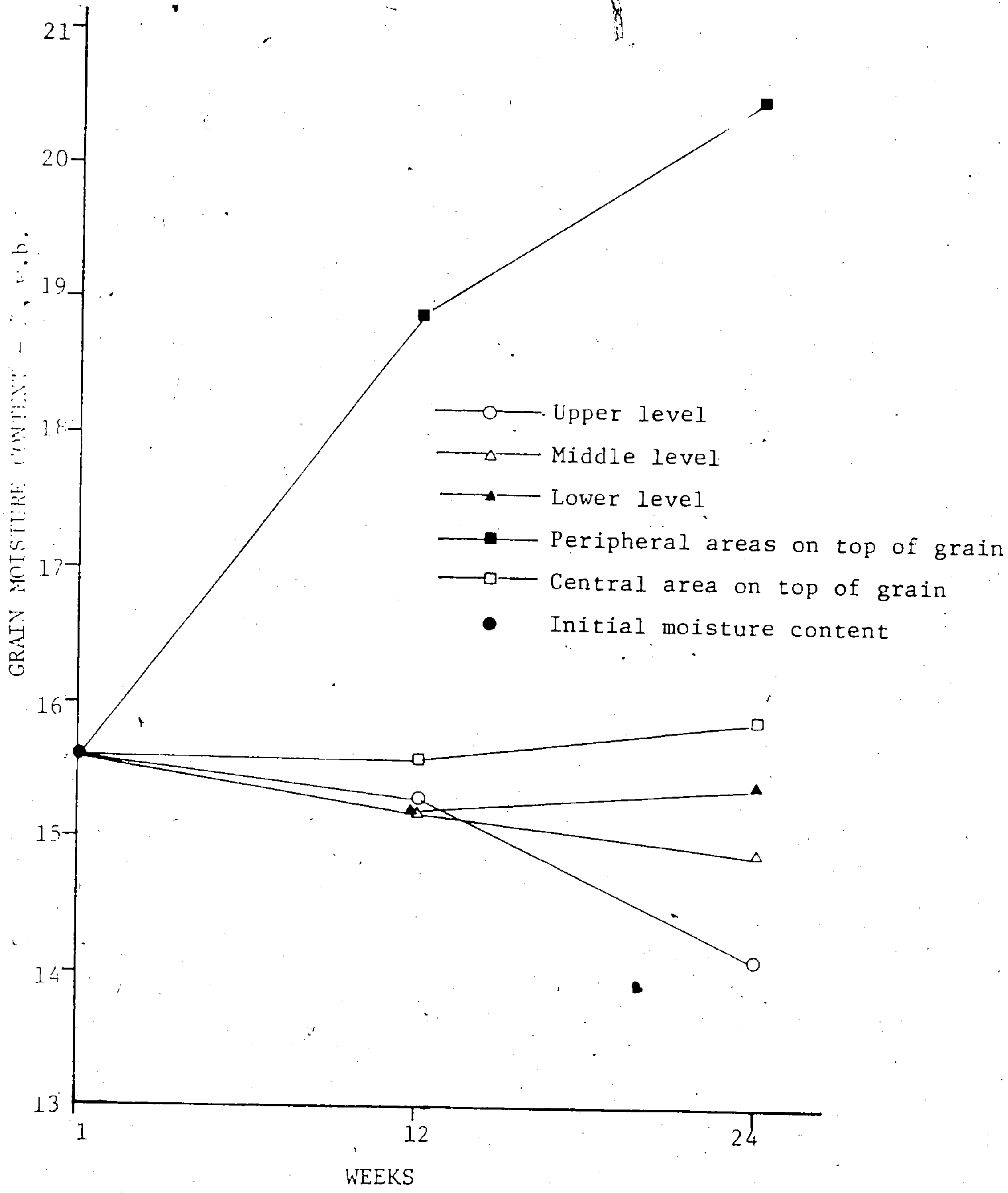


FIGURE 5.11c: Grain moisture content variations at the various levels within the grain bulk during storage in concrete bin 3.

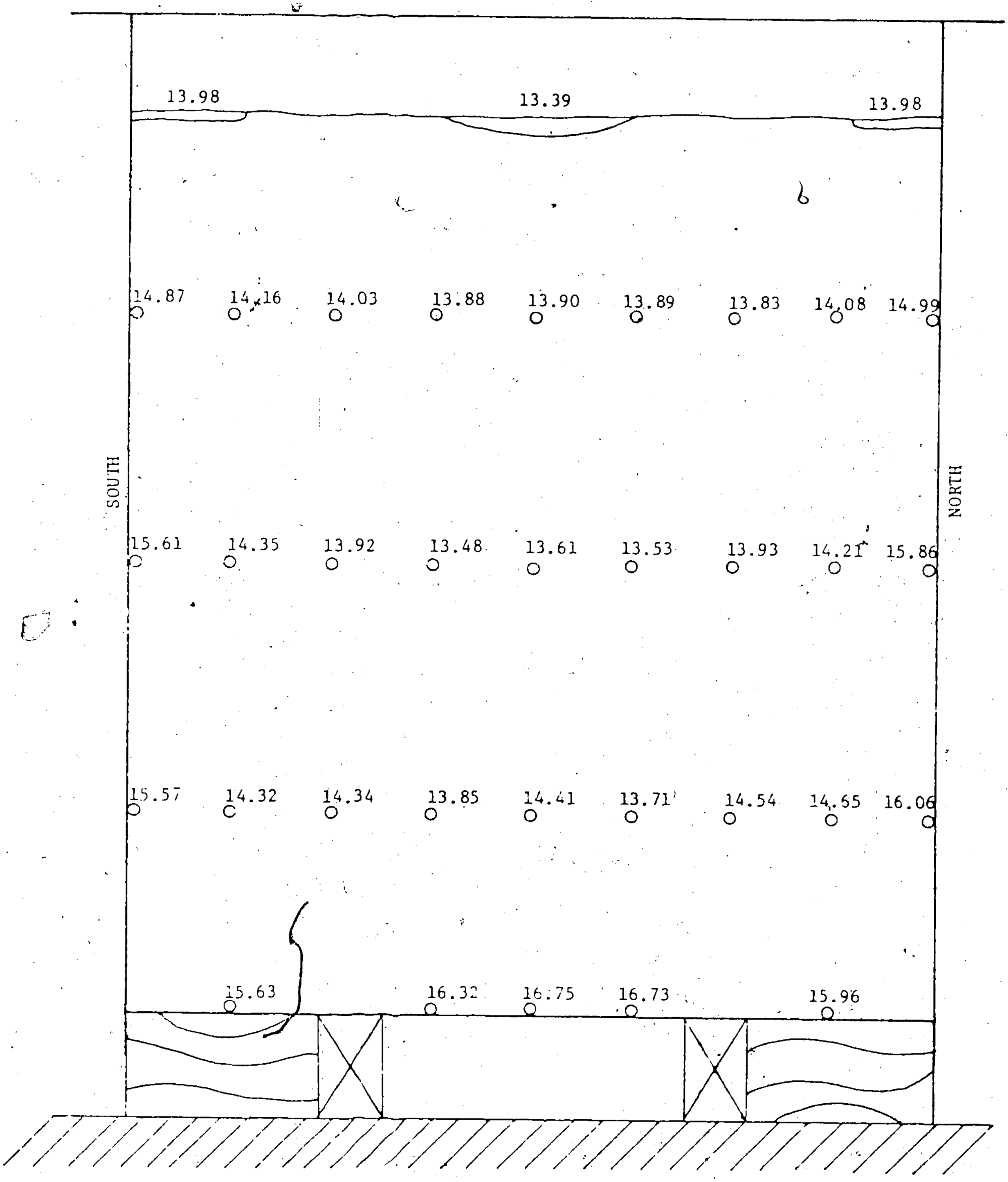


FIGURE 5.12a: Mean grain moisture tents (%, w.b.) for the plywood bins at various points on a centrally located north-south vertical plane. Spacing between points on each level was 15.2 cm.

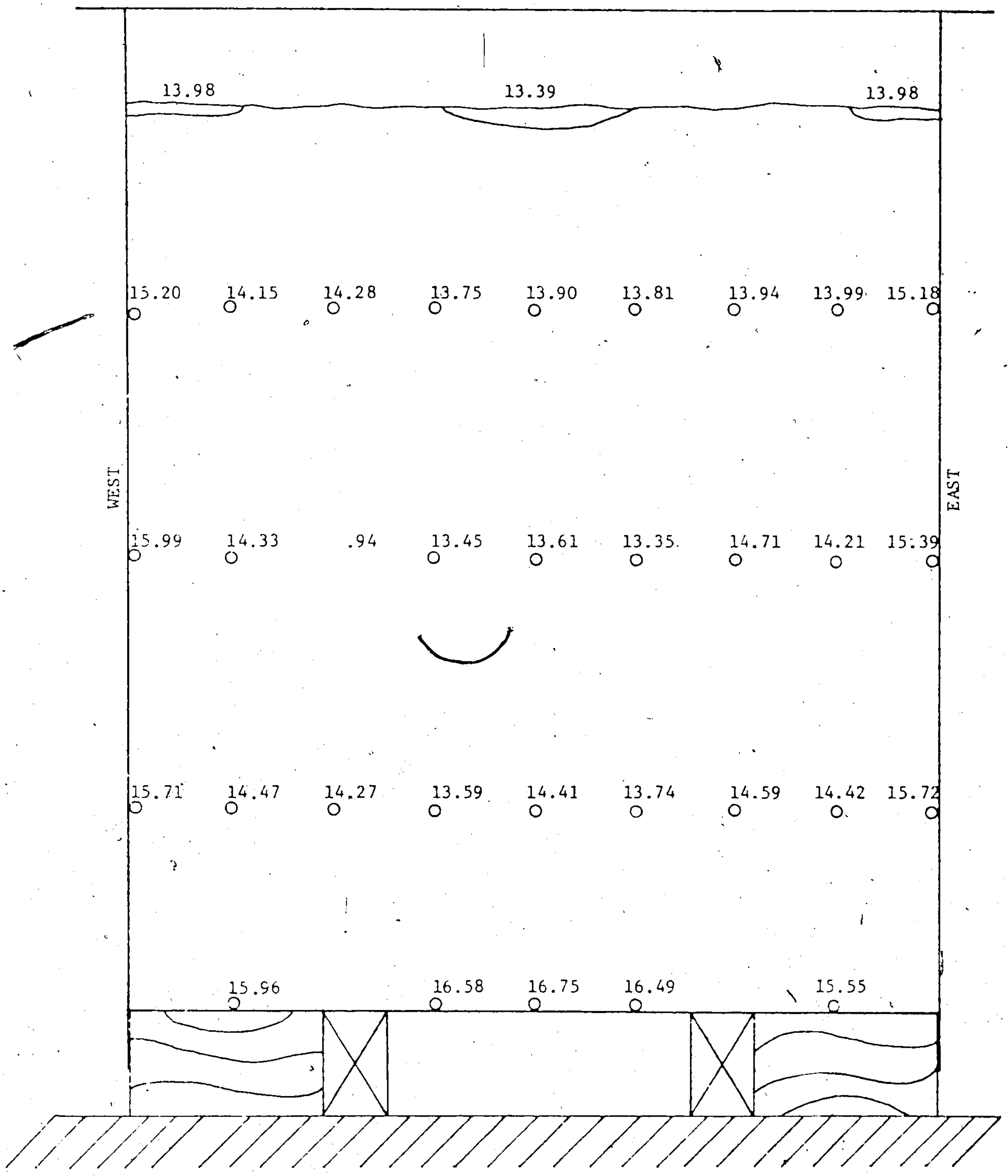


FIGURE 5.12b: Mean grain moisture contents (%, w.b.) for the plywood bins at various points on a centrally located east-west vertical plane. Spacing between points on each level was 15.2 cm.

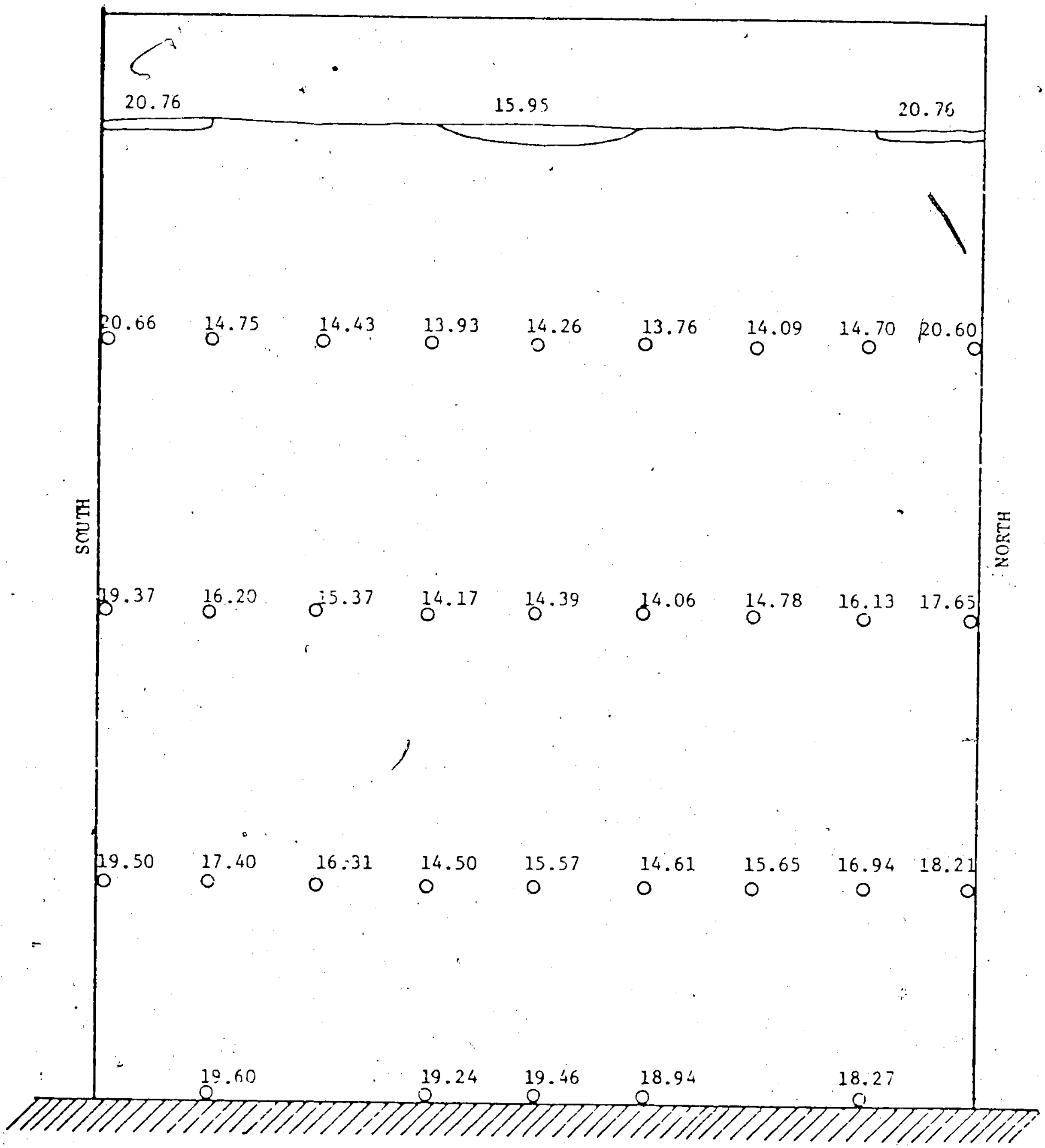


FIGURE 5.13a: Mean grain moisture contents (%, w.b.) for the concrete bins at various points on a centrally located north-south vertical plane. Spacing between points on each level was 15.2 cm.

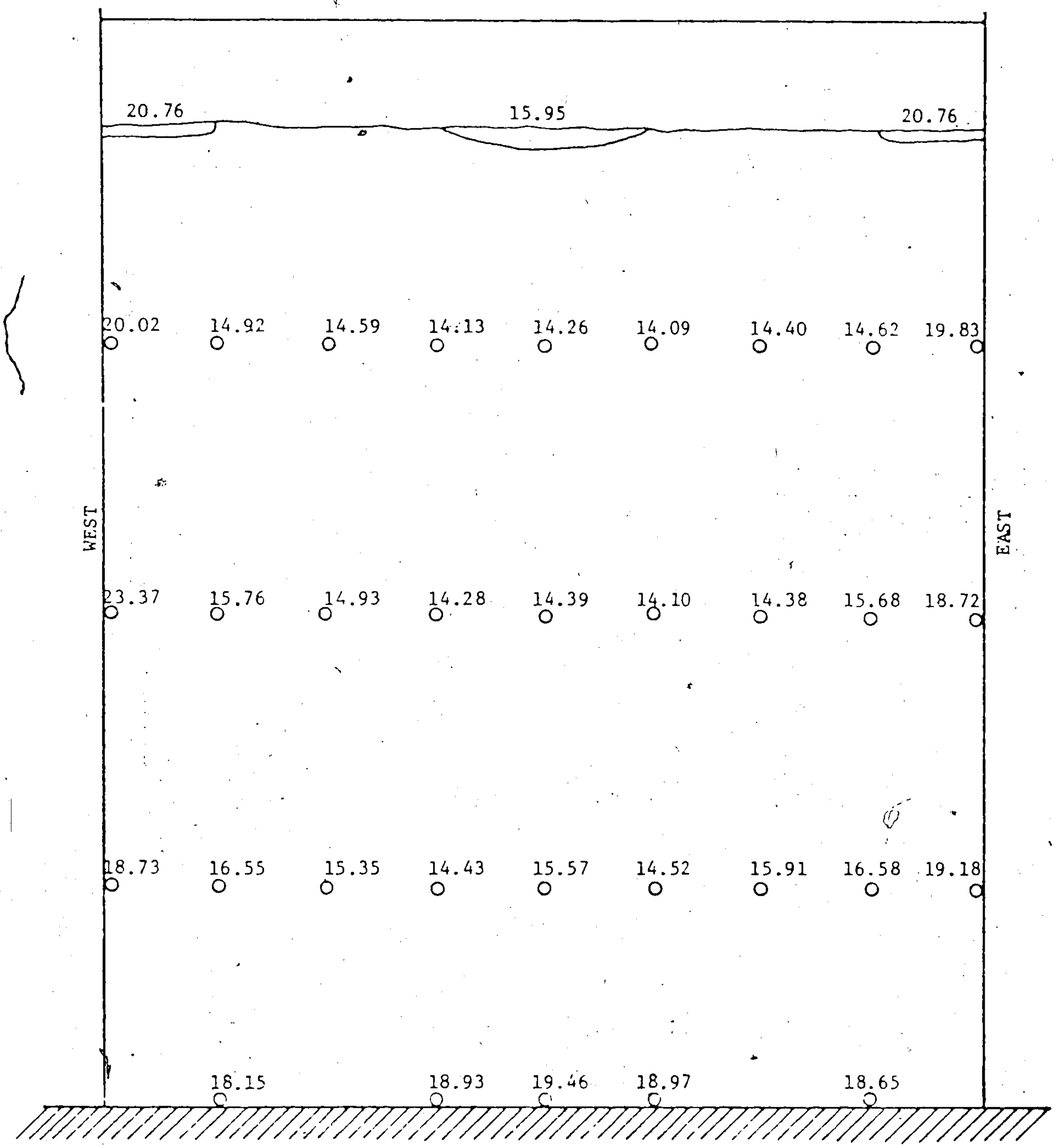


FIGURE 5.13b: Mean grain moisture contents (%, w.b.) for the concrete bins at various points on a centrally located east-west vertical plane. Spacing between points on each level was 15.2 cm.

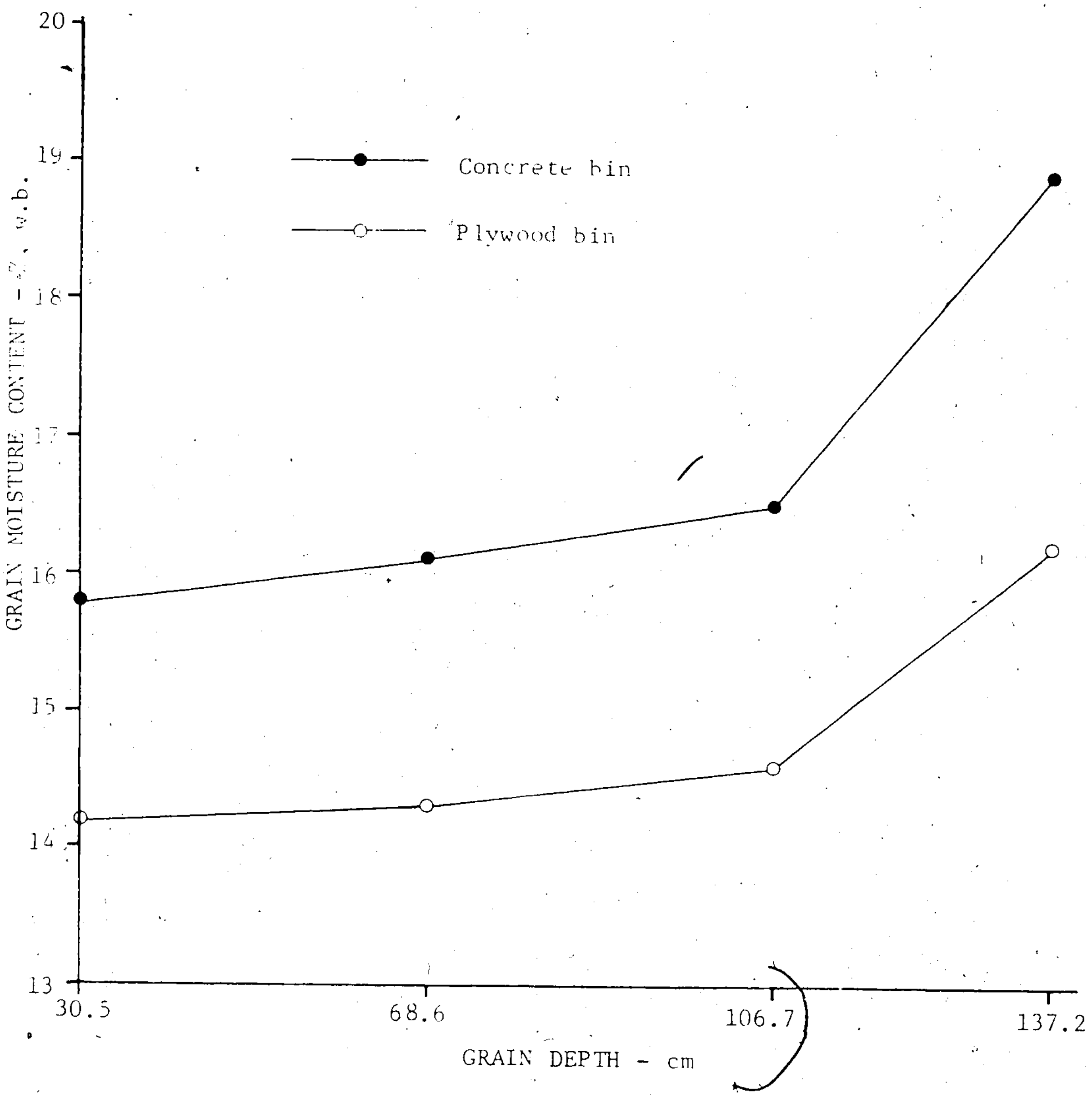


FIGURE 5.14: Mean grain moisture content variations with depth of grain at the end of 24 weeks of storage in concrete and plywood bins.

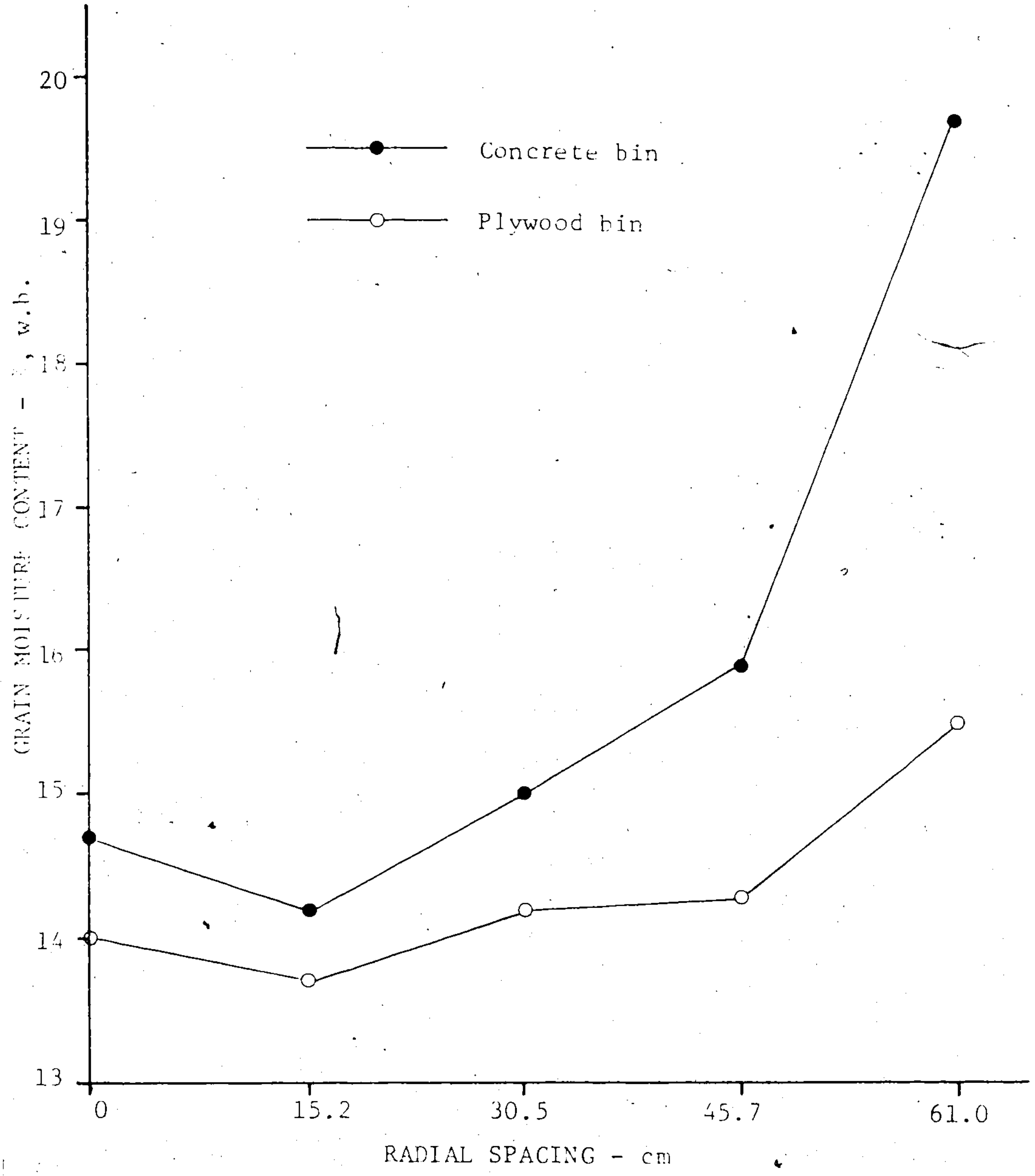


FIGURE 5.15: Mean grain moisture content variations with radial spacing at the end of 24 weeks of storage in concrete and plywood bins.

5.2.2.1 Analysis of Variance - Grain Moisture

The data used for the analysis of variance are presented in Appendix VI. These values have been derived from the original data in Appendices IV and V for the purpose of the statistical analysis. The data used for this analysis related only to the 24 thermocouple locations and did not include data arising from sampling elsewhere in the bins.

Results of the analysis of variance, Table 5.5, indicated that there were highly significant differences in the main effects of material, position, level and period of storage (weeks). The first-order interactions of Position X Material (PM), Level X Material (LM), Position X Level (PL), Week X Material (WM) and Week X Level (WL) were all found to be highly significant. Generally in this analysis of variance for grain moisture, the first-order and second-order interactions were significant. The second-order interaction of Week X Position X Material (WPM) and the only third-order interaction, however, were not significant. The significant results obtained for these interactions verified that the combined effects of the specified factors are independent of each other.

5.2.3 Ambient Temperature, Solar Intensity and Relative Humidity

The results of the simulated temperatures are illustrated in Figure 5.16. The simulated temperatures, however, were slightly higher than the desired temperatures for the Kumasi area, that is, between latitudes 6° and 7° N, with a standard error of the mean difference of 0.39°C.

Occasional shutdown of the cooling unit for repairs at certain stages of the experiment and frequent opening of the environmental room door, with subsequent air exchanges, rendered the control of the

TABLE 5.5: ANALYSIS OF VARIANCE RESULTS FOR GRAIN MOISTURE CONTENTS AT THE 12TH AND 24TH WEEKS OF STORAGE.

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARES	F-VALUE	PROBABILITY
Material (M)	1	8.41	31.49	0.005**
B/M (Bin/M)	4	0.27		
Position (P)	1	13.52	97.15	0.0006***
PM	1	2.88	20.69	0.0104*
PB/M	4	0.14		
Level (L)	2	0.96	19.55	0.0008***
LM	2	0.74	15.02	0.002**
LB/M	8	0.05		
PL	2	0.82	27.26	0.0003***
PLM	2	0.20	6.54	0.0207*
PLB/M	8	0.03		
Week (W)	1	8.54	94.62	0.0006***
WM	1	2.42	26.81	0.0066**
WB/M	4	0.09		
WP	1	1.03	14.73	0.0185*
WPM	1	0.35	4.98	0.0895
WPB/M	4	0.07		
WL	2	0.72	17.48	0.0012**
WLM	2	0144	10.77	0.0054**
WLB/M	8	0.04		
WLP	2	0.32	5.84	0.0273*
WLPM	2	0.07	1.33	0.3166
WLPB/M	8	0.06		
TOTAL	71			

* Significant at .05 probability level
** Significant at .01 probability level
*** Significant at .001 probability level

ambient temperature to within the required temperature range quite difficult. The simulated temperatures, however, were within the temperature ranges recorded at some of the major areas in Ghana (Figure 5.16). There was no significant difference between the actual and the simulated temperature values as indicated by a 't' test outlined by Zalik (1971).

The average simulated hourly temperatures of the day, that is

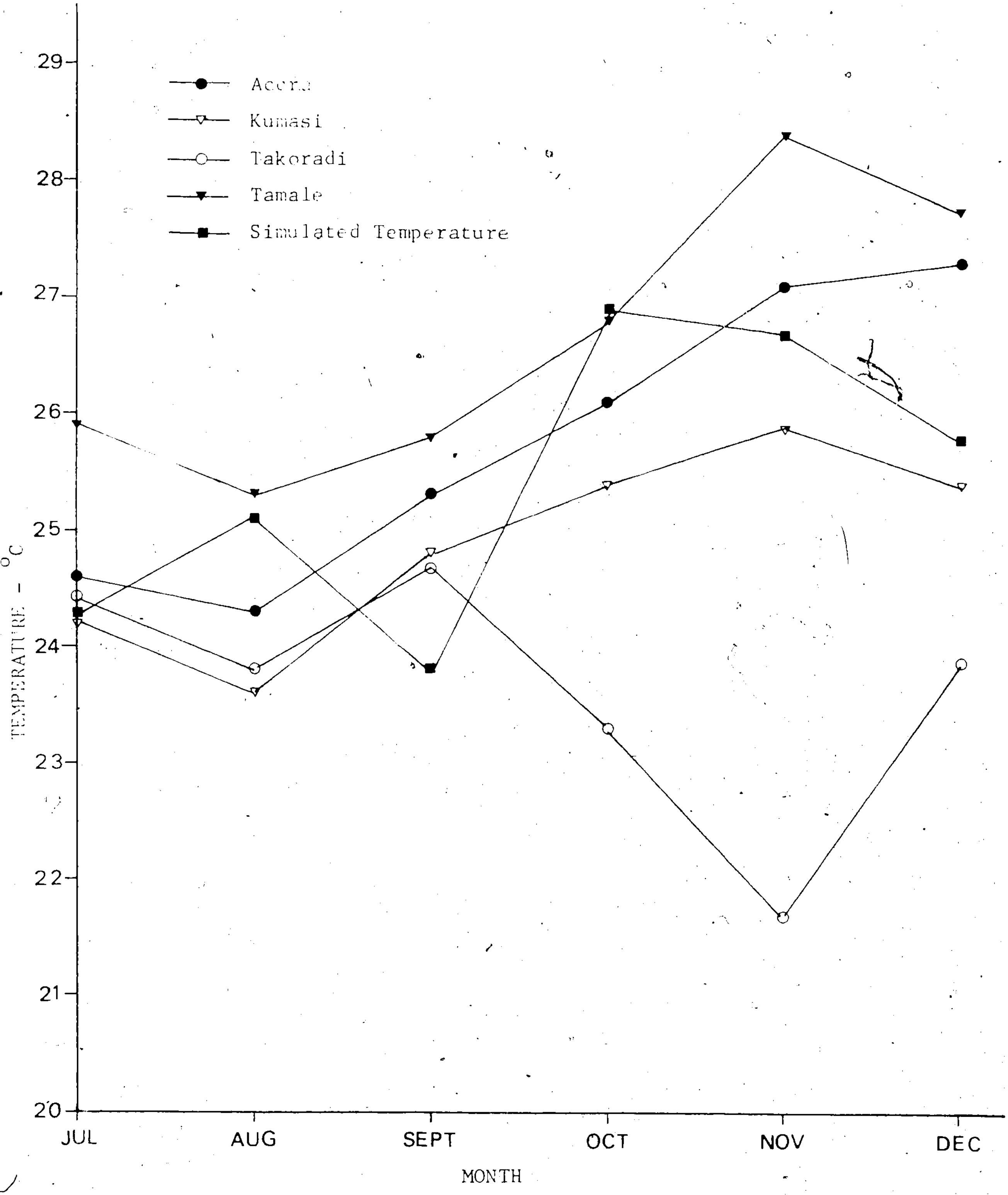


FIGURE 5.16: Mean monthly temperatures and the simulated monthly temperatures for the desired months of storage, July to December.

hourly variations in ambient temperatures, for the six storage months are illustrated in Figure 5.17. During late evenings and early mornings the temperatures were relatively low. As the "sun" came up, that is, when the heat lamps were switched on after 8 a.m., the environment was warmed up. Temperatures rose gradually to a peak between 12 noon and 2 p.m. The ambient air started cooling off (temperatures started to decline) after about 3 p.m. and by late night and early hours of the morning temperatures were relatively low again.

The solar intensity value obtained from the heat lamps averaged 4.6 mW/cm^2. The average obtained from the computerized energy calculations was 7.0 mW/cm^2 for 0% overcast skies in a region of latitude 7^{o}N. The simulated average value, therefore, was 66% of the computerized value. The simulated solar intensity could have been raised by getting the heat lamps closer to the bins but this exercise was limited by the workable space in the environmental room. The raising or lowering of the heat lamp frames was restricted by the trusses in the vertical direction and by the walls of the room in the horizontal direction. The observed values of solar intensity, however, were acceptable as in reality a condition of 0% overcast skies does not normally prevail in the simulated area. There is usually a certain percentage of cloud cover in most tropical skies. Solar intensity values are, therefore, lower than the expected values obtained from the computerized calculations based on 0% overcast skies. Hence, the actual values prevailing during the experiment could be considered a practical representation of the actual solar intensity conditions that prevails in the tropical environment.

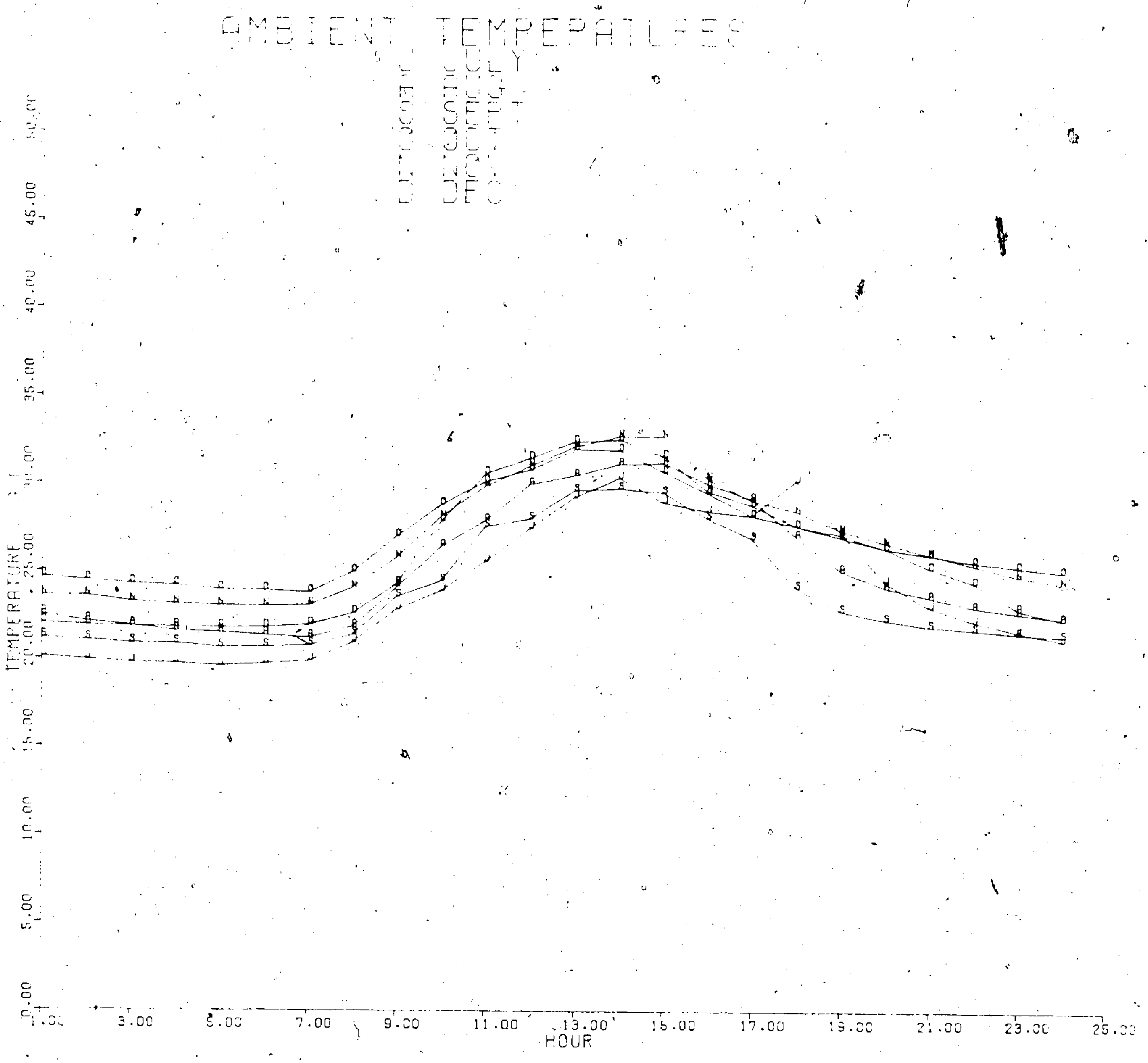


FIGURE 5.17: Simulated hourly mean ambient temperature variations for the desired months, July to December.

Simulated relative humidity values are illustrated in Figure 5.18. The relative humidity values obtained for the storage months of July to September were below 70%. The attainment and maintenance of desired relative humidity values were very difficult in the early stages of the experiment. Frequent breakdowns of the humidifier and the subsequent frequent entry by service personnel coupled with leakage of cold, dry winter air around the doors caused a considerable loss of moisture from the experimental room. Also condensation on the walls and on the doors was another source of moisture loss. Towards the end of the winter months when the outside air warmed up and its specific humidity level increased, moisture loss from the experimental environment was minimal and the attainment of the right relative humidity range was then possible.

5.3 Discussion of Results.

5.3.1 Temperature

Temperature, both ambient and within storage structures, is a major factor influencing the condition of food in storage. The effect of the environmental temperature on the grain is given by the response of the grain temperature to the external temperature. In this study, the response by the various areas within the grain bulk to ambient temperature was slow initially. There was also no remarkable differential temperature responses in areas within the grain bulk. This situation, however, pertained to grain within the plywood bins (Figures 5.3, 5.4 and 5.5). Temperature gradients in the areas marked by thermocouple levels, became more pronounced after the fifth week and after the grain had become warmer than the environment.

The grain within the concrete bins did not show any

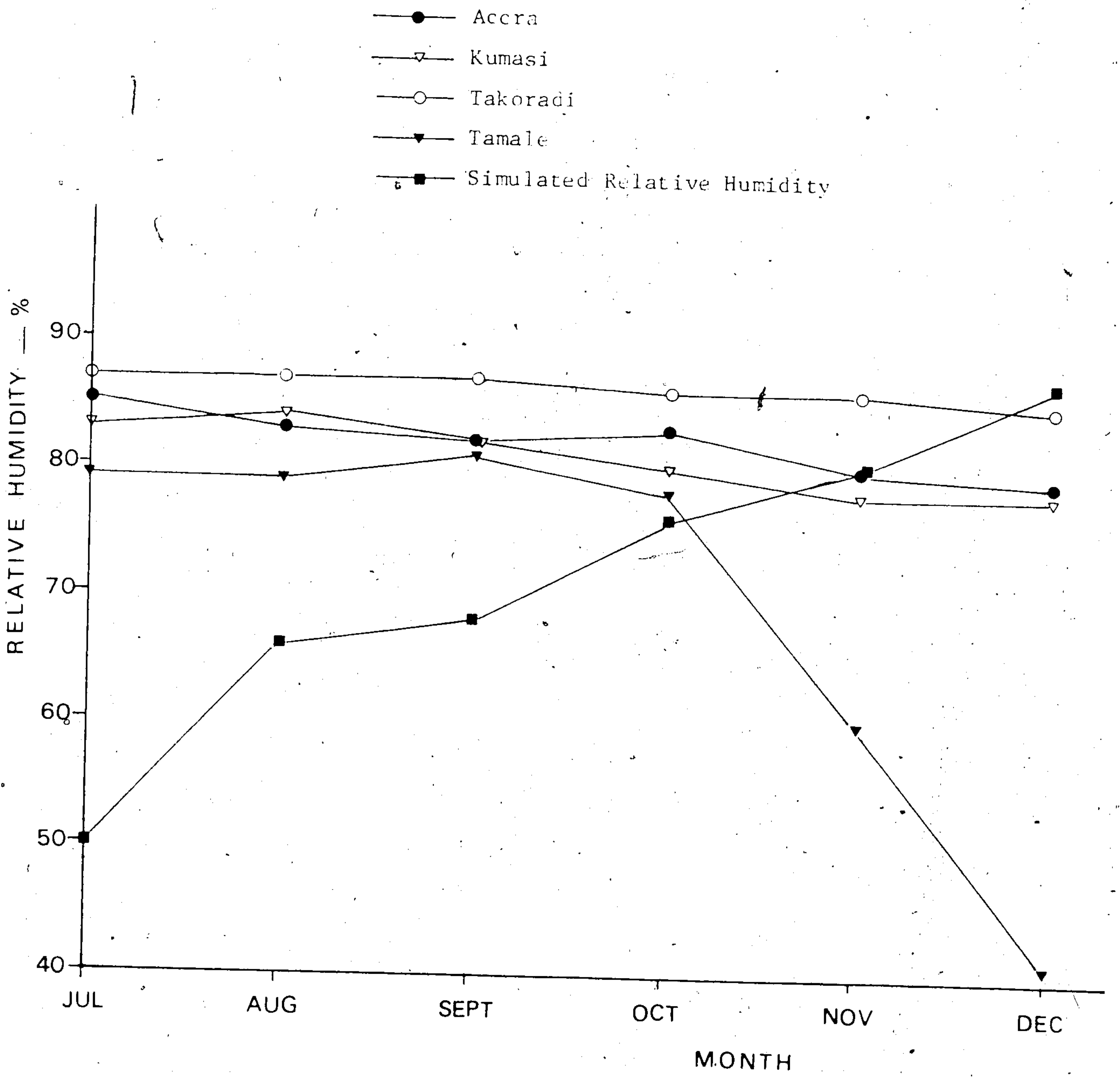


FIGURE 5.18: Mean monthly relative humidity and the simulated monthly relative humidity variations for the desired months of storage, July to December.

temperature gradients at any stage of the storage experiment (Figures 5.6, 5.7 and 5.8). During the initial stages of the experiment, the rate of temperature rise at the monitored points within the grain was high and also uniform. This overall grain response to temperature might have been influenced more by an internal heat source than by an external heat source. This implies that there might have been heating of grain by both internal and external heat sources in this experiment. However, the internal heat possibly was generated faster, at a more constant rate and to a much greater extent, thus offsetting the influence of the intermittent external heat source on the grain bulk.

Increase in storage fungal populations and subsequent high biological activity within the grain bulk could have been the major cause of heating of the grain. Walker (1967) revealed that *A. glaucus*, if growing rapidly, can increase the temperature of the grain at least to 35°C to 40°C. Once the moisture content of the grain exceeds 15.0 to 15.5%, *A. glaucus* can grow and, given optimum conditions, can increase the moisture content and temperature of the grain rapidly. The other source of internal heat is respiration by the seeds themselves. There is, however, no evidence that this factor is involved in heating of a grain bulk to other than a very minor degree.

The effect of a high ambient temperature is manifested by warmer peripheral areas and cooler interior parts of the grain as the heat is transmitted slowly towards the inner parts of the grain bulk. This results in a temperature gradient between the peripheral and the inner areas.

Dry maize is known to be a good insulating material, its thermal conducitivity increasing with increased temperature and increased moisture content (Milton and Jarret, 1970). The rise in grain temperature in this experiment may be due solely to biological activities inside the grain bulk. These exothermic processes may have taken place at all parts or areas within the grain bulk and at almost a uniform rate. This is evident particularly in the concrete bins. Theoretically, an external heat source should affect the grain in the concrete bins more than the grain in the plywood bins because concrete has a higher thermal conductivity than plywood. The thermal conductivities for concrete and plywood (Douglas Fir) are 0.0108 and 0.0016 watts/cm^2/°C/cm respectively (ASHRAE, 1965). The temperature gradients that were observed inside the plywood bins but not the concrete bins suggested the influence of another factor or factors apart from thermal conductivities per se.

As a result of localized biological activity within the grain bins, grain temperatures and moisture contents were increased. These changes also would result in increased partial pressures of water vapour within the bin atmospheres. Even though the ambient conditions in this experiment were humid, especially during the second half of the experiment, ultimately the bin vapour pressure most probably exceeded that of the ambient air with the result that vapour pressure gradients were established across the bin walls such that moisture as water vapour would tend to move from the bins to the ambient air. From the result of this study, the vapour permeance of the dense concrete used in the manufacture of the pipes apparently was appreciably lower than that of the plywood. The apparently superior vapour transmittance characteristics of the plywood would appear to have reduced the vapour pressure differential across the wall sufficiently to minimize the risk of condensation due to diurnal temperature fluctuations and to limit the rate of microbial activity in the vicinity of the walls to less than that experienced in the concrete bins. This reduction in microbial activity in turn would slow down the rate of heat and moisture production that created in the first instance conditions favourable to the deterioration of the grain.

The differential temperature increases in the various areas within the plywood bins may be attributed to the combined effect of an external heat source and water vapour transmission across the plywood material. Any deposition of moisture and its absorption by the plywood material would increase its moisture content and specific gravity. A relationship between thermal conductivity (k), moisture content (MC) and specific gravity (SG) is represented as: $k = SG\,[1.4 + 0.028\,(MC)] + 0.16$. This shows that an increase in moisture content or specific gravity reduces plywood's heat insulating properties (Payne, 1971). The thermal conductivity of the plywood used in this study very probably was reduced by moisture absorption from both the grain and the ambient air. External heat from the ambient, as a result of reduction in heat insulating properties, may have been transmitted slowly towards the interior parts of the grain bulk. This was evident in the higher temperatures recorded in the outer core or region (formed by the cylindrical arrangement of the thermocouples) than the temperatures obtained in the inner core or region.

When the temperature of the grain was below that of the ambient air, the rate of temperature increase within the grain bulk was very high and external temperature variations had no effect on the grain temperature (Figures 5.3 to 5.8). The grain temperature became stabilized after attaining a temperature that was higher than that of the ambient. The overall temperature gain, above the ambient temperature, by the grain mass in all the bins during the experiment averaged 2.3°C.

An earlier experiment at Kumasi, Ghana, with a plywood bin covered with thatch, showed an average 3.3°C rise in the grain bulk (about 14.7%, w.b.) temperature over a storage period of 22 days (Lamptey and Vas, 1976). Results from this experiment also indicated that grain temperature varied directly with the hourly ambient temperatures.

The hot spots which developed in the plywood bins, probably as a result of increased microbial activity, did not persist for any length of time. The heat generated in those areas was dissipated quickly. The mass of grain stored was relatively very small, and heat therefore had a short flow-path from the centre of the bulk to the outside and vice versa. The cooler night temperatures also might have assisted in dissipating this additional heat overnight.

The purpose of the analysis of variance was to test for significance or statistical differences that existed between the temperatures for the main factors considered for the storage experiment (Table 5.3). Of the main effects, the difference between the mean weekly temperatures of the grain bulk was highly significant. This is an indication that there was an appreciable heating up of the grain over the storage period. There was no significant difference between materials, that is, the direct effect of the plywood and the concrete on grain temperatures was similar. The rather high mean square value for the interaction between bin and material that was used as the error term produced a very low F-value for the material term. Consequently, the probability level was over 90%. This high value also indicated that the variation between bins of the same material was very pronounced. This variation is illustrated in Figure 5.19 and Table 5.6. The differences or variations between grain temperatures may be

TABLE 5.6: SELECTED MEANS OF GRAIN TEMPERATURES (^{o}C) USED FOR THE ANALYSIS OF VARIANCE.

(a) MATERIAL:

Plywood - 27.8
Concrete - 27.7

(b) MATERIAL X BIN:

Material	Bin		
	1	2	3
Plywood	26.7	29.0	27.6
Concrete	27.0	28.4	27.7

(c) POSITION:

Outer - 27.6
Inner - 27.8

(d) LEVEL:

Upper - 27.7
Middle - 28.0
Lower - 27.5

(e) POSITION X MATERIAL:

		Plywood	Concrete
Outer	-	27.9	27.7
Inner	-	28.0	27.7

(f) LEVEL X MATERIAL

		Plywood	Concrete
Upper	-	27.7	27.7
Middle	-	28.3	27.7
Lower	-	27.3	27.7

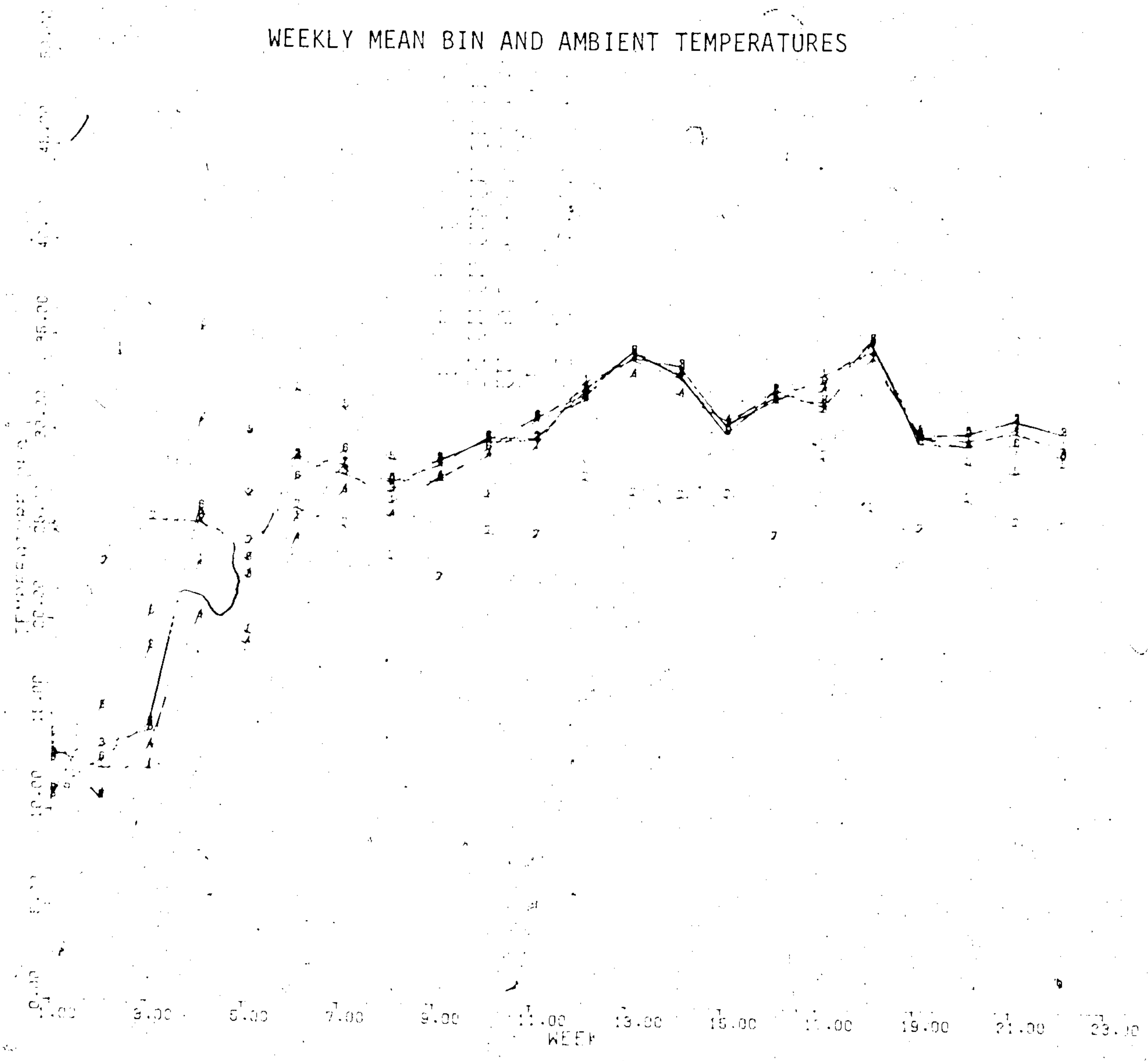


FIGURE 5.19: Overall weekly mean temperature variations for the storage bins and the ambient. CB = Concrete Bin, PB = Plywood Bin and AMB = Ambient

attributed in part, at least, to bin location within the environmental room. The two bins (P1 and C1) which were located very close to the services door and which, therefore, were affected by cold air drafts from the opening of the door, recorded relatively lower temperatures. The other two bins (P2 and C2) were located farther away from the door (Figure 4.6) and thus were not affected very much by cold air drafts from the outside. These bins registered relatively high temperatures. These temperature variations between bins, however, were noticed during the early weeks of the storage experiment when the natural outside temperatures were very low and the grain temperature was lower than that of the simulated ambient. Bin temperature variations became very small about midway during the storage experiment (Figure 5.19).

The significance of first-order interactions (Table 5.3) is an indication that the temperature differences that existed in the plywood and concrete bins at their respective radial spacings and depth of grain (vertical spacings or levels) were both independent of the interplay of the specified factors. Temperature gradients, therefore, existed in both the "Y" and "X" directions. The significance that existed in the first-order interactions demonstrated also that there is no interplay of each of the main effects in the interaction for the generation and conduction of heat within the grain bulk. In other words, these main effects specified in the interactions are independent of each other in effecting temperature differences in the grain bulk. The only difference in temperature exhibited in a concrete bin was in terms of weekly variations and not in terms of any of the other main effects.

The analysis of variance at two levels of temperature (Table 5.4), that is, grain and ambient temperatures, indicated that there were very high weekly temperature variations. These weekly variations have been illustrated in Figure 15.19. Temperature differences between the grain and the ambient were highly significant. The overall average temperatures for the grain bulk and the ambient were 27.7°C and 25.4°C respectively. The interaction of Week X Temperature (WT) was also highly significant. The inference that may be drawn from these significant temperature differences between the grain bulk and the ambient is that the heating of grain in storage was affected more by an internal heat source than by an external heat source, that is, the ambient temperature.

5.3.2 Moisture

Hall (1957) has indicated that redistribution of moisture occurs when grain is stored. The movement of moisture inside a grain bulk is along a heat flow path and is usually in the vapour phase. The direction of flow of heat and, therefore, the flow of moisture depends on the temperature gradient between the grain bulk and ambient temperatures, as illustrated in Figure 3.3. The deposition of moisture in cooler areas initiates the spoilage of grain.

In this experiment, the grain went into storage at an average moisture content of 15.6% and at a rather low temperature of about 7°C. With the ambient temperature warmer than the grain temperature, the expectation is that the convectional currents, developed as a result of temperature differentials, move dowhwards in the centre of the grain bulk and upwards along the peripheral areas of the bin. Moisture accumulation and spoilage should start, therefore, at the central areas on the floor of the bin (Figure 3.3b) during the early stages of the experiment when the ambient temperature was warmer than the grain temperature. The results of the final moisture analysis indicate that moisture accumulation was not restricted to the central portion of the bin floor but also occurred in the peripheral area (Figures 5.14 and 5.15). Moisture accumulation in the peripheral areas possibly may be the result of a lateral flow of water vapour along a partial vapour pressure gradient that existed between grain bulk and the ambient air. Diurnal ambient temperature variations may be an effective mechanism that caused a deposition of moisture in the peripheral areas. During the night when the "sun" had set, and ambient temperatures were cooler than grain temperatures, the peripheral air would cool and moisture may have condensed in that area of the bin.

Also, during the cool nights, a possible lateral heat flow, by conduction and radiation, towards the periphery of the grain bulk might be effective. The short flow path in the bins used to the peripheral regions may be a factor to this lateral flow of heat and, therefore, water vapour. The accumulation of moisture in the lower levels might be due to convectional air currents created within the grain bulk as a result of the establishment of a temperature gradient between the grain and the ambient air. The cooler air in the peripheral areas of the grain moved in a downward direction and deposited its moisture in the lower cooler areas. The higher moisture content values in the lower levels along the walls and the floor also could be attributed to gravitational movement of condensed moisture.

In general, the rate of moisture accumulation in areas inside the plywood bins was less than in the case of the concrete bins. This brings into play the levels of vapour transmitting properties possessed by the two materials, that is, the plywood and the concrete. The concrete had an absorption capacity* of not more than 9% of the dry mass. This is very low and prevented virtually any moisture exchange between the grain inside and the concrete bin and the environment. Moisture accumulation on the inside walls of the concrete appeared to be very high and, consequently, this probably provided the trigger for the decay of the kernels in the peripheral area. The moisture build-up on the walls perhaps may have slowed down moisture movement through the concrete and hence contributed further to the development of the higher moisture areas in these bins.

The vapour permeability coefficient of plywood is generally low. Relatively, however, this vapour permeance coefficient for plywood may have been higher than that of the concrete used for the experiment. The factors and process involved in the establishment of vapour gradient within the grain bulk and the movement of vapour towards the outside are as discussed previously. The concrete pipes used had been designed specifically to hold water. Again, there may have been a higher rate of exchange of vapour between the grain and the environment via the seals between the lid and wall although both types of bins seemed to be similarly sealed. The two materials, plywood and concrete, contained grain, however, from the same stock maintained under the same conditions of temperature and humidity. Any difference between the behaviour of the grain in the plywood and the concrete bins, therefore, would appear to be the result of differences in their physical properties. The concrete bins did not show any temperature variations within the grain, yet

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* As rated by the manufacturer.

moisture redistribution within the bins was very remarkable. Temperature variation was only on a weekly (or daily) basis and not on the basis of location or position within the grain bulk. The inference based on this finding is that moisture redistribution did not depend solely on temperature gradient within the grain bulk during storage but also on the overall temperature gradient between the grain bulk and the outside temperature.

The few hot spots that developed in certain locations in, for instance, the plywood bin 2, must be the result of the presence of high moisture pockets in those locations. There may have been an increased biological activity, such as respiration, by fungi, pests and grain kernels, which resulted in the creation of heat sources in those areas.

The highly significant difference that was exhibited between the plywood and the concrete with respect to moisture redistribution, within the grain bulk each bin contained, was an indication that moisture most probably was lost through the plywood. The suspected loss of moisture from the peripheral areas of the plywood may have created a very steep moisture gradient between the central portion of the grain bulk and the periphery. More moisture migrated towards the plywood bin wall, especially during the cooler night temperature, where it was condensed and probably absorbed into the plywood itself. The means of selected factors used for the analysis of variance are presented in Table 5.7. As portrayed in Table 5.7, the difference in moisture contents of the grain in the inner cores or positions of plywood and concrete bins is about 0.5% while a corresponding figure for the outer cores is as high as 1.27%. In general, moisture loss from the plywood bins was higher than the loss from the concrete units.

Moisture differences with respect to depth of grain or level were highly significant. Variation in moisture at the three levels (layers) within the plywood bins was very small. The range between the lower and upper moisture levels is only 0.15% (Table 5.7).

TABLE 5.7: MEANS OF SELECTED FACTORS FOR THE ANALYSIS OF VARIANCE FOR GRAIN MOISTURE CONTENT (%).

MATERIAL:

Plywood - 14.51
Concrete - 15.19

LEVEL: (Plywood and Concrete)

Upper - 14.67
Middle - 14.82
Lower - 15.07

POSITION: (Plywood and Concrete)

Outer - 15.29
Inner - 14.42

WEEKS: (Plywood and Concrete)

Twelve - 15.20
Twenty-four - 14.51

LEVEL X MATERIAL:

		Plywood	Concrete
Upper	-	14.53	14.82
Middle	-	14.43	15.22
Lower	-	14.58	15.55

POSITION X MATERIAL:

		Plywood	Concrete
Outer	-	14.74	15.83
Inner	-	14.28	14.56

POSITION AND LEVEL:

Position	Level		
	Upper	Middle	Lower
Outer	14.89	15.38	15.59
Inner	14.45	14.27	14.54

Similarly, the range for the corresponding levels within the concrete bins was 0.73%. The difference between the highest moisture levels in the three layers within both the plywood and concrete bins was 0.97%. The fact that the concrete bins had no floor of their own but were set on the concrete floor of the room could have provided a much cooler floor than the plywood bins which had their own floor of the same material. Air circulation under the plywood bins was effective, and any moisture absorption from the floor by the grain thus was prevented. The high moisture values obtained for the lower depths of the concrete bins can be attributed to two main factors. Firstly, the cooler floor enhanced downward vapour movement, as indicated in Figure 3.3b, towards that region. The rate of condensation and, therefore, moisture deposition in that region of concrete was high. Secondly, although the possibility is small, there might have been some moisture absorption from the floor into the grain bulk and that could raise the moisture level of the grain in the floor area. On the whole, the rate of lateral movement inside the grain bulk was higher than the rate of downward movement in all bins.

There was a decrease in moisture over the entire storage period. The difference in moisture levels at 12 and 24 weeks of storage was highly significant. Drying occurred, therefore, at the 26 sample points (24 thermocouple locations plus the peripheral areas and the central portion on top of the grain). By the middle of the experimental period the mean grain moisture content had dropped by about 0.4%, and by the end of the experiment the total drop in moisture was about 1.1% (Table 5.7), that is, the drop in grain moisture content was only 0.4% during the first 12 weeks of storage while the drop for the last half of the storage period was 0.7%. A general observation was that drying occurred in the centre of the grain bulk, with wetting of the peripheral grain.

The first-order interactions of the main effects of Material, Position, Level and Week were all significant as shown in Table 5.5. The interaction of Position and Level was highly significant, which signified that the movements of moisture in the vertical and horizontal directions occurred absolutely independent of each other under the specified storage conditions.

6. SUMMARY AND CONCLUSIONS

A summary of results obtained in this study, and the conclusions drawn, are as follows:

1. Temperature gradients, established in the grain within the plywood bins during storage, were influenced by both external and internal heat sources. Although no such gradients developed within the concrete bins, the rise in grain temperature was attributable to the internal heat source only, that is, to microbial activity.
2. Grain temperature differences that developed within the plywood bins were dependent on depth (level), radial location (spacing) and length of storage. Temperatures within the concrete bins were time-dependent only.
3. The inner section of the grain within the plywood bins was significantly warmer ($P < 0.05$) than the outer section, while the middle level (depth) was significantly warmer ($P < 0.05$) than either the upper or lower level. The upper level was significantly warmer ($P < 0.05$) than the lower.
4. Hot spots that developed within the grain were localized in the centre of the bins. These hot spots, particularly within the plywood bins, did not persist for any length of time. The highest hot spot temperature was 42.0°C. Hot spots that might have developed within the grain in the concrete bins were not readily apparent.
5. The heating of grain in all bins was fast when the grain temperature was lower than the ambient. The rate of heating slowed down considerably after the grain had attained overall bin

temperatures higher than the ambient. The mean ambient temperature over the storage experiment was 25.4°C while the corresponding values [illegible] the grain in the plywood bins and in the concrete bins were both 26.6°C.

6. The overall grain temperature in both bin types was significantly higher ($P < 0.01$) than the ambient temperature. The initial mean grain and ambient temperatures were 7.0°C and 23.0°C respectively. Corresponding figures at 12th and 24th weeks of storage were 30.2°C and 24.6°C, 29.6°C and 25.4°C respectivley.
7. There were no significant temperature variations within any of the bins after the first half (12 weeks) of the storage period.
8. After the grain temperatures had stabilized and after 12 weeks of storage, the rise or fall in the grain bulk temperatures followed the rise or fall in ambient temperature but with approximately one week time lag.
9. The two materials (plywood and concrete) did not exhibit any significant difference in their effect on the temperatures of the grain they stored.
10. The mean moisture content of grain within the concrete bins at the end of 24 weeks of storage was significantly higher ($P < 0.01$) than that for the plywood bins. Initial moisture content of the grain was 15.6%, w.b.. Overall mean moisture contents of grain within the plywood and concrete bins were 15.0% and 15.4%, respectively, after the grain had been in store for 12 weeks. By the end of the 24 weeks of storage the respective mean moisture contents for grain within the plywood and concrete bins were 14.0% and 15.0%, wet basis.

11. The differences in grain moisture contents between the two bin types at the different depths, radial spacings and length of storage were significant ($P < 0.001$). The interaction of radial position and depth was significant ($P < 0.001$) which signified that the lateral and vertical movements of moisture within the grain during storage were independent of each other.
12. Moisture deposition was high both on the floor and around the walls of the bins under hot humid conditions. More moisture was deposited on the floor and walls of the concrete bin than the plywood. The high moisture level on the wall of the concrete bin initiated caking and decaying processes. The degree of caking and decay decreased towards the centre of the grain bulk.
13. Redistribution of moisture within a grain bulk during storage depends on factors such as temperature gradients within the grain, temperature gradients between the grain and the ambient air and partial vapour pressure gradients between the grain and the ambient air. These factors may either act singly or in combinations with one another.
14. The storage fungi _Penicillium_ and _Aspergillus species_ proliferate and dominate when grain at 15.6%, w.b., is stored under hot and humid (tropical) conditions. The initial counts for these fungi indicated 99% infestation by _Penicillium_ and 8% infestation by _Aspergillus_. These infestation rates increased to a mean of almost 100% in both fungi by the end of the experiment.
15. The maize stored in the plywood bins was relatively sound at the end of the experiment compared to that stored in the concrete bins.

7. SUGGESTIONS FOR FURTHER STUDIES

The experience gained in this investigation would suggest the need for further study in the following storage areas:

1. Plywood as a material exhibited considerable potential for use in bin construction for maize storages under hot humid conditions. Further work should be aimed at reducing its vapour resistance and establishing how this would affect its ability to store fairly moist maize in such an environment.
2. Further trials using plywood to store maize for a range of practical moisture contents should be investigated to establish optimum safe moisture levels.
3. The problem of high moisture levels, in tropical areas, in the form of vapour and molecular water has to be considered before any material is selected for the storage of grain, especially, in the open. Plywood should be used under a roof or should be sheltered from tropical rains when it is being used to store grain. Consideration should be given to the treatment of the plywood to reduce its water absorption capacity while increasing its vapour permeability. A study to investigate the treatment of plywood with a material that repels water but transmits vapour should be encouraged.
4. Solar radiation can increase temperature gradients within grain storages and hence influence the quality of the grain. In this regard, the colour of materials used in bin construction and the effects of shade should be investigated.

5. Various thicknesses of plywood or ordinary sawn timber planks or boards can be used in the construction of grain storage bins. Since all timber species differ in their mechanical and physical properties, a study in this subject may possibly reveal an appropriate combination of timber species and size (thickness) for the safe storage of grain under hot humid conditions.
6. Heat radiation and moisture absorption from the soil are other factors that may affect the quality of grain in store especially if the bin is set directly on the ground or on a floor without a vapour barrier. A study into different types of floor supports and their effects on heat and/or moisture transmission from the soil into the grain should be considered. This type of study may be appropriate for the two materials considered in this thesis.
7. The concrete pipe concept of grain storage should be pursued further. The nature of the pipe should be modified to suit storage structure demands. The walls may have to be less dense or more porous and permeable to water vapour from within the grain.
8. An improved concrete bin should also be tried with varying g[illegible] moisture levels to find out an optimum moisture content level for safe storage of grain.

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APPENDIX I: METEOROLOGICAL DATA FOR THE MAJOR CENTRES OF GHANA (Ghana Meteorological Services, Bull. No. 65418, Kumasi, 1976)--MEAN VALUES

STATION	J	F	M	A	M	J	J	A	S	O	N	D
	Temperature (°C)											
Accra	27.3	27.7	27.8	27.7	27.0	25.7	24.6	24.3	25.3	26.1	27.1	27.3
Kumasi	25.2	26.7	26.9	26.7	26.4	25.4	24.2	23.6	24.8	25.4	25.9	25.4
Takoradi	26.1	26.7	27.2	27.1	26.3	25.5	24.4	23.8	24.7	23.3	21.7	23.9
Tamale	28.0	29.7	30.6	30.1	28.4	26.8	25.9	25.3	25.8	26.8	28.4	27.7
	Relative humidity (%)											
Accra	79	77	77	80	82	85	85	83	82	83	80	79
Kumasi	74	71	75	77	79	82	83	84	82	80	78	78
Takoradi	85	85	83	83	87	87	87	87	87	86	86	85
Tamale	33	35	49	60	69	74	79	79	81	78	60	41
	Precipitation (mm)											
Accra	16	37	73	82	145	193	49	16	40	80	38	18
Kumasi	26	65	136	139	191	223	113	74	170	201	95	32
Takoradi	31	38	80	102	250	288	87	35	48	131	77	38
Tamale	2	9	51	88	121	132	128	189	217	98	13	5

APPENDIX I: continued.

STATION	J	F	M	A	M	J	J	A	S	O	N	D
	Total duration of sunshine (h)											
Accra	208	210	226	219	214	147	149	149	168	214	246	233
Kumasi	180	182	208	207	201	144	99	71	102	158	201	192
Takoradi	205	207	229	216	189	120	~~158~~	130	126	192	243	226
Tamale	263	238	251	243	248	210	164	136	159	254	288	270
	Atmospheric pressure (mb)											
Accra	10.6	10.3	10.0	10.3	11.5	13.4	14.2	13.9	12.9	12.2	11.1	10.7
Kumasi	10.7	10.3	9.9	10.2	11.5	13.5	14.2	13.9	12.9	12.1	11.2	10.9
Takoradi	10.4	10.1	9.8	10.0	11.2	13.2	14.1	13.8	12.9	11.9	10.9	10.5
Tamale	10.3	9.3	8.7	9.1	10.6	12.7	13.2	12.8	12.3	11.7	10.6	10.5

APPENDIX II. TABLE OF TEMPERATURE (^{o}C) DATA USED FOR ANALYSIS OF VARIANCE--CALCULATED MEANS.

		OUTER CORE			INNER CORE			
BIN	WEEK	UPPER	MIDDLE	LOWER	UPPER	MIDDLE	LOWER	AMBIENT
11*	1	13.1	13.1	13.1	13.1	13.1	13.1	24.7
11	2	12.2	12.2	12.2	12.2	12.2	12.2	22.9
11	3	12.2	12.2	12.2	12.2	12.2	12.2	25.3
11	4	23.1	23.1	23.1	23.1	23.1	23.1	25.2
11	5	19.4	19.4	19.4	19.4	19.4	19.4	24.1
11	6	25.4	25.4	25.4	25.4	25.4	25.4	26.0
11	7	28.2	28.2	28.2	28.2	28.2	28.2	25.1
11	8	26.3	26.3	26.3	26.3	26.3	26.3	23.4
11	9	27.6	27.6	27.6	27.6	27.6	27.6	22.3
11	10	26.7	26.7	26.7	26.7	26.7	26.7	24.8
11	11	29.3	29.3	29.3	29.3	29.3	29.3	24.6
11	12	32.8	32.8	32.8	32.8	32.8	32.8	27.7
11	13	34.0	34.0	34.0	34.0	34.0	34.0	26.9
11	14	33.1	33.1	33.1	33.1	33.1	33.1	26.8
11	15	30.7	30.7	30.7	30.7	30.7	30.7	26.9
11	16	31.9	31.9	31.9	31.9	31.9	31.9	24.7
11	17	33.3	33.3	33.3	33.3	33.3	33.3	29.0
11	18	34.6	34.6	34.6	34.6	34.6	34.6	26.3
11	19	30.1	30.1	30.1	30.1	30.1	30.1	25.2
11	20	30.0	30.0	30.0	30.0	30.0	30.0	26.9
11	21	30.4	30.4	30.4	30.4	30.4	30.4	25.6
11	22	29.7	29.7	29.7	29.7	29.7	29.7	25.4
12	1	13.9	13.9	13.9	13.9	13.9	13.9	24.7
12	2	10.6	10.6	10.6	10.6	10.6	10.6	22.9
12	3	18.5	18.5	18.5	18.5	18.5	18.5	25.3
12	4	30.6	30.6	30.6	30.6	30.6	30.6	25.2
12	5	26.6	26.6	26.6	26.6	26.6	26.6	24.1
12	6	28.7	28.7	28.7	28.7	28.7	28.7	26.0
12	7	28.3	28.3	28.3	28.3	28.3	28.3	25.1
12	8	27.4	27.4	27.4	27.4	27.4	27.4	23.4
12	9	28.3	28.3	28.3	28.3	28.3	28.3	22.3
12	10	29.8	29.8	29.8	29.8	29.8	29.8	24.8
12	11	29.8	29.8	29.8	29.8	29.8	29.8	24.6
12	12	32.3	32.3	32.3	32.3	32.3	32.3	27.7
12	13	34.4	34.4	34.4	34.4	34.4	34.4	26.9
12	14	33.7	33.7	33.7	33.7	33.7	33.7	26.8
12	15	30.6	30.6	30.6	30.6	30.6	30.6	26.9
12	16	32.5	32.5	32.5	32.5	32.5	32.5	24.7
12	17	31.7	31.7	31.7	31.7	31.7	31.7	29.0
12	18	34.2	34.2	34.2	34.2	34.2	34.2	26.3
12	19	30.3	30.3	30.3	30.3	30.3	30.3	25.2
11	20	30.3	30.3	30.3	30.3	30.3	30.3	26.9
12	21	31.1	31.1	31.1	31.1	31.1	31.1	25.6
12	22	30.4	30.4	30.4	30.4	30.4	30.4	25.4

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* The first digit refers to the material (concrete--1; plywood--2) and the second refers to the bin number. For example, 11 refers to concrete bin 1.

APPENDIX II. Continued.

		OUTER CORE			INNER CORE			
BIN	WEEK	UPPER	MIDDLE	LOWER	UPPER	MIDDLE	LOWER	AMBIENT
13	1	12.8	12.8	12.8	12.8	12.8	12.8	24.7
13	2	13.3	13.3	13.3	13.3	13.3	13.3	22.9
13	3	14.2	14.2	14.2	14.2	14.2	14.2	25.3
13	4	25.4	25.4	25.4	25.4	25.4	25.4	25.2
13	5	22.3	22.3	22.3	22.3	22.3	22.3	24.1
13	6	28.6	28.6	28.6	28.6	28.6	28.6	26.0
13	7	27.8	27.8	27.8	27.8	27.8	27.8	25.1
13	8	26.9	26.9	26.9	26.9	26.9	26.9	23.4
13	9	28.6	28.6	28.6	28.6	28.6	28.6	22.3
13	10	29.6	29.6	29.6	29.6	29.6	29.6	24.8
13	11	29.7	29.7	29.7	29.7	29.7	29.7	24.6
13	12	32.0	32.0	32.0	32.0	32.0	32.0	27.7
13	13	34.1	34.1	34.1	34.1	34.1	34.1	26.9
13	14	33.7	33.7	33.7	33.7	33.7	33.7	26.8
13	15	30.6	30.6	30.6	30.6	30.6	30.6	26.9
13	16	31.9	31.9	31.9	31.9	31.9	31.9	24.7
13	17	31.4	31.4	31.4	31.4	31.4	31.4	29.0
13	18	35.0	35.0	35.0	35.0	35.0	35.0	26.3
13	19	30.1	30.1	30.1	30.1	30.1	30.1	25.2
13	20	30.4	30.4	30.4	30.4	30.4	30.4	26.9
13	21	31.0	31.0	31.0	31.0	31.0	31.0	25.6
13	22	30.4	30.4	30.4	30.4	30.4	30.4	25.4
21	1	12.8	13.3	11.4	13.3	13.3	11.1	24.7
21	2	10.7	10.7	10.7	10.7	10.7	10.7	22.9
21	3	12.7	13.1	13.7	12.8	13.9	13.4	25.3
21	4	20.2	20.6	20.3	20.5	20.3	19.3	25.2
21	5	17.8	18.9	18.9	18.8	20.4	17.8	24.1
21	6	22.9	25.0	24.4	25.0	25.5	22.6	26.0
21	7	25.3	27.8	26.7	27.8	28.3	25.3	25.1
21	8	24.0	26.4	25.2	26.4	27.4	24.0	23.4
21	9	26.0	28.9	26.5	29.2	29.9	25.9	22.3
21	10	26.3	30.2	27.7	30.4	31.5	26.7	24.8
21	11	29.1	32.0	29.6	32.0	32.4	29.1	24.6
21	12	31.3	32.2	31.5	32.2	32.2	31.3	27.7
21	13	33.4	33.4	32.2	33.4	33.4	33.4	26.9
21	14	32.2	32.2	32.2	32.2	32.2	32.2	26.8
21	15	30.9	30.9	30.9	30.9	30.9	30.9	26.9
21	16	32.1	32.1	32.1	32.1	32.1	32.1	24.7
21	17	32.5	32.5	32.5	32.5	32.5	32.5	29.0
21	18	35.0	35.2	35.1	35.2	35.2	35.0	26.3
21	19	30.1	30.1	30.1	30.1	30.2	30.1	25.2
21	20	29.7	29.7	29.7	29.7	29.7	29.7	26.9
21	21	30.6	30.6	30.6	30.6	30.6	30.6	25.6
21	22	29.3	29.3	29.3	29.3	29.3	29.3	25.4

APPENDIX II. Continued.

		OUTER CORE			INNER CORE			
BIN	WEEK	UPPER	MIDDLE	LOWER	UPPER	MIDDLE	LOWER	AMBIENT
22	1	10.6	10.6	10.6	10.6	10.6	10.6	24.7
22	2	15.3	15.3	15.3	15.3	15.3	15.3	22.9
22	3	20.2	20.4	20.3	20.4	20.4	20.1	25.3
22	4	34.8	35.2	34.3	35.2	37.2	36.1	25.2
22	5	29.9	29.9	29.4	29.9	30.1	30.6	24.1
22	6	30.7	33.0	30.3	34.0	34.6	30.6	26.0
22	7	31.1	31.1	31.3	31.1	32.1	31.1	25.1
22	8	27.9	28.2	28.4	28.0	30.9	27.9	23.4
22	9	28.0	28.2	28.1	28.7	29.9	28.0	22.3
22	10	29.6	29.8	29.6	29.8	30.1	29.4	24.8
22	11	30.8	30.8	30.8	30.8	30.9	30.8	24.6
22	12	32.4	32.4	32.4	32.4	32.4	32.4	27.7
22	13	34.4	34.4	34.4	34.4	34.4	34.4	26.9
22	14	33.2	33.2	33.2	33.2	33.2	33.2	26.8
22	15	30.2	30.2	30.2	30.2	30.2	30.2	26.9
22	16	32.1	32.1	32.1	32.1	32.1	32.1	24.7
22	17	31.9	31.9	31.9	31.9	31.9	31.9	29.0
22	18	35.2	35.2	35.2	35.2	35.2	35.2	26.3
22	19	30.4	30.4	30.4	30.4	30.4	30.4	25.2
22	20	28.8	28.8	28.8	28.8	28.8	28.8	26.9
22	21	28.3	28.3	28.3	28.3	28.3	28.3	25.6
22	22	28.7	28.7	28.7	28.7	28.7	28.7	25.4
23	1	10.9	10.9	10.9	10.7	10.9	10.9	24.7
23	2	11.4	13.9	11.4	13.6	13.9	11.4	22.9
23	3	14.3	14.5	15.0	14.2	15.0	13.8	25.3
23	4	24.6	27.4	25.4	27.6	27.1	23.3	25.2
23	5	20.4	24.6	22.6	24.4	27.1	20.4	24.1
23	6	25.0	29.3	26.3	29.3	30.0	25.0	26.0
23	7	26.7	30.3	28.0	30.5	31.9	26.7	25.1
23	8	25.0	28.9	26.4	29.0	31.0	25.0	23.4
23	9	25.4	29.0	25.8	29.6	29.9	25.4	22.3
23	10	27.1	30.6	27.8	31.3	31.3	27.1	24.8
23	11	29.4	32.2	29.7	32.3	32.3	29.4	24.6
23	12	31.3	32.8	31.3	33.0	32.8	31.3	27.7
23	13	34.2	34.6	34.2	34.6	34.6	34.2	26.9
23	14	33.1	33.4	33.2	33.4	33.4	33.2	26.8
23	15	30.0	30.4	30.1	30.4	30.6	30.0	26.9
23	16	32.4	32.4	32.4	32.4	32.4	32.4	24.7
23	17	32.9	32.9	32.9	32.9	32.9	32.9	29.0
23	18	34.7	35.7	34.8	35.9	35.7	34.7	26.3
23	19	29.1	30.3	29.2	30.3	31.0	29.1	25.2
23	20	29.7	29.7	29.7	29.7	29.7	29.7	26.9
23	21	29.8	29.8	29.8	29.8	29.8	29.8	25.6
23	22	29.2	29.2	29.2	29.2	29.2	29.2	25.4

APPENDIX III. TABLE OF SIMULATED AMBIENT TEMPERATURES AND RELATIVE HUMIDITIES--CALCULATED MEANS.

MONTH	AMBIENT TEMPERATURE, ^{o}C	R.H., %
JULY	24.3	50
AUGUST	25.1	66
SEPTEMBER	23.8	68
OCTOBER	26.9	76
NOVEMBER	26.7	80
DECEMBER	25.8	87

APPENDIX IV. RESULTS OF GRAIN MOISTURE ANALYSIS AT THE END OF 12TH WEEK OF STORAGE.

LOCATION	MEAN MOISTURE CONTENT, %					
	P1	P2	P3	C1	C2	C3
1	15.31	15.11	15.58	16.01	15.23	15.32
2	15.07	14.99	15.21	15.69	15.59	15.65
3	15.55	14.88	15.64	15.51	15.03	15.52
4	15.00	14.90	15.57	15.83	15.24	15.44
5	14.90	14.91	14.77	15.13	14.80	15.10
6	15.33	15.20	14.60	14.78	14.93	14.97
7	15.21	14.89	14.80	15.17	14.98	15.26
8	15.25	14.74	14.96	15.08	15.17	14.93
9	15.43	14.86	15.42	15.60	15.83	15.68
10	14.69	14.15	15.04	16.15	16.38	15.84
11	15.21	15.36	15.98	16.72	15.96	15.56
12	15.38	14.87	15.84	16.54	17.04	15.44
13	14.87	14.88	14.44	14.65	14.35	14.65
14	14.96	14.80	14.42	14.61	14.79	14.67
15	14.75	14.80	14.44	14.60	14.87	14.95
16	14.80	14.62	14.32	14.45	14.79	14.80
17	13.95	15.14	15.21	15.54	15.46	15.52
18	15.43	15.86	15.50	15.00	16.28	15.92
19	14.82	15.46	15.28	15.89	15.73	15.57
20	15.00	15.50	15.80	15.90	17.25	15.59
21	14.59	15.05	14.64	14.71	14.78	14.65
22	15.18	15.00	14.38	15.16	15.05	15.07
23	15.35	14.87	15.18	15.20	15.65	15.01
24	15.13	14.91	14.62	14.89	15.43	14.65
Top of grain (centre)	13.67	14.66	13.93	15.73	15.23	15.61
Top of grain (periphery)	14.54	14.70	14.18	19.83	18.89	18.89

APPENDIX V. RESULTS OF GRAIN MOISTURE ANALYSIS AT THE END OF 24TH WEEK OF STORAGE

LOCATION	MEAN MOISTURE CONTENT, %					
	P1	P2	P3	C1	C2	C3
1	13.93	13.88	14.63	15.25	15.16	14.35
2	13.78	13.96	14.49	14.57	14.92	14.60
3	13.72	13.96	14.25	14.52	14.75	14.59
4	13.96	13.81	14.70	14.83	14.88	14.53
5	13.74	13.92	13.58	13.98	14.69	13.73
6	13.87	13.47	14.34	13.53	13.97	13.78
7	13.72	13.73	13.97	13.90	14.67	14.69
8	13.75	14.02	13.86	13.61	14.44	13.75
9	13.70	14.26	15.04	16.38	15.86	15.30
10	14.03	14.34	14.26	15.70	16.78	15.92
11	14.02	14.43	14.19	15.19	16.02	15.83
12	14.58	13.87	14.61	15.78	16.33	16.49
13	13.09	13.95	13.31	14.70	14.33	13.80
14	13.50	13.57	13.51	13.83	14.61	13.75
15	13.16	13.49	13.39	13.86	14.49	13.95
16	13.38	13.66	14.41	13.99	14.72	13.81
17	14.08	14.61	14.73	17.24	16.56	15.85
18	14.84	14.77	14.33	16.59	17.70	16.53
19	14.16	14.81	14.28	16.96	16.55	16.23
20	14.07	14.33	14.56	18.01	17.26	16.94
21	13.19	13.96	13.61	14.41	14.50	14.38
22	13.54	13.88	13.72	14.59	14.90	14.35
23	13.43	13.98	13.81	14.37	14.87	14.32
24	13.57	13.98	14.00	14.47	14.75	14.28
Top of grain (centre)	13.11	13.62	13.45	15.74	16.19	15.92
Top of grain (periphery)	13.41	14.13	14.41	19.67	22.13	20.49

APPENDIX VI. GRAIN MOISTURE DATA (%, WET BASIS) USED FOR THE ANALYSIS OF VARIANCE.

LAYER OR POSITION	MEAN MOISTURE CONTENT, %					
	P1	P2	P3	C1	C2	C3
12th WEEK						
(1) LAYER:-						
UPPER	15.2	15.0	15.1	15.4	15.1	15.3
MIDDLE	15.0	14.8	15.0	15.4	15.5	15.2
LOWER	14.9	15.2	15.1	15.3	15.7	15.2
(2) POSITION:-						
OUTER UPPER	15.2	15.0	15.5	15.8	15.3	15.5
OUTER MIDDLE	15.2	14.8	15.6	16.3	16.3	15.6
OUTER LOWER	14.8	15.5	15.4	15.6	16.2	15.6
INNER UPPER	15.2	14.9	14.8	15.0	15.0	15.1
INNER MIDDLE	14.8	14.8	14.4	14.6	14.7	14.8
INNER LOWER	15.1	15.0	14.7	15.0	15.2	14.8
24th WEEK						
(1) LAYER:-						
UPPER	13.8	13.8	14.2	14.3	14.7	14.1
MIDDLE	13.7	13.9	14.1	14.9	15.4	14.9
LOWER	13.9	14.3	14.1	15.8	15.9	15.4
(2) POSITION:-						
OUTER UPPER	13.8	13.9	14.5	14.8	14.9	14.5
OUTER MIDDLE	14.1	14.2	14.5	15.8	16.2	15.9
OUTER LOWER	14.3	14.6	14.5	17.2	17.0	16.4
INNER UPPER	13.8	13.8	13.9	13.8	14.4	13.7
INNER MIDDLE	13.3	13.7	13.7	14.1	14.5	13.8
INNER LOWER	13.4	13.9	13.8	14.5	14.8	14.3