ABSTRACT

NATURAL DRYING OF CASSAVA

by

Gonzalo Roa

Annual world-wide transactions of dried cassava, Manihot esculenta Crantz, to the European Economic Community (EEC) from developing countries are estimated at one hundred million dollars. The product is used for animal feed mixes and both foreign and local markes are expected to increase rapidly. Cassava production surpases 100 million tons per year . Is is presently dried in the developing countries by slow, and risky operational systems.

Experimental and analytical studies were conducted with several cassava varieties and different ages to evaluate conventional and newly designed systems of drying cassava under variable weather conditions. Differences in the systems were attributed to the relative positions of the layers of the product (in mesh trays) and the floor, or to different geometrical forms of the cassava particles. The influence of varieties and ages were not significant in drying.

A mathematical model predicated about 1700 hourly experimental moisture content values with an average arror of 2 percent, wet basis. The final moisture content value at the end of a drying day could also be predicated within three percent (w.b.) by using average atmospheric conditions. Sensitivity analysis based on the model indicated that the

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maximum weight of a layer that could be dried deterioration, depended mainly on the size of the particles, the saturation water vapor pressure deficit, and the wind velocity.

A vertical type of drier consisting of two parallel wire panels was found to be the most efficient form of drying cassava. The cassava layer takes nearly all the required energy for evaporation from the air enthalpy. The vertical position of the layer and an adequate product geometry permits the air to move through the product and creates turbulence. The air gives off part of its sensible heat and removes the evaporated moisture. When the vertical cassava layer is covered by a roof, the drying rates are not reduced; thus drying may continue overnight or while raining. Drying of the product in horizontal, elevated mesh trays is a less efficient method than the vertical drier, but more efficient than the conventional system of drying cassava on concrete floors.

Two low-cost cutting mechanisms were designed to produce rectangular cassava bars, the optimum geometric figure found among several studied, including those traditionally used. The mechanisms are : (a) a manual press , and (b) a disc cutter which produces a geometry resembling the rectangular bars at a rate of 240 kg/hr when operated by a bicycle pedal mechanism, o about 500 kg/hr when operated by a motor.

A deterioration criterion was established to recommend maximum

densities allowed to dry safely as a function of average environmental conditions and the the type of drying system. A cost analysis of a commercial operation was made based on the experimental work and the simulated results. Limitations of natural drying of cassava are summarized and suggestions for future work in this field are made. The original data and the computer programs of analysis are included in the appendices.

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To my mother, Zoila

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LIST OF SYMBOLS

Symbol	
A	surface area, m^2
a_i	i=1, 2, 3, ...constants without physical meaning
b_i	i=0, 1, 2, ...functional relationship used to shorten equation (6.2)
i	i=0, 1, 2, ... index
C	water vapor concentration in air, kg/m^3
C_a	water vapor concentration in undisturbed air, kg/m^3
C_s	water vapor concentration in air at the surface, kg/m^3
c_a	specific heat of dry air, J/kg °C
c_i	i=0, 1, 2, ... functional relationship used to shorten equation (6.2)
c_m	air specific heat, J/kg °C
c_p	product specific heat, J/kg °C
c_v	water vapor specific heat, J/kg °C
c_w	water specific heat, J/kg °C
D	density or initial load per unit area, kg/m^2
D_e	diffusion coefficient of water in a porous body, m^2/sec
D_{max}	maximum density allowable to dry without deterioration, kg/m^2
d_b	bulk density, g/cm^3
d_i	i=1, 2, 3, ... constants without physical meaning

Symbol	
d_i'	i=1, 2 constants without physical meaning
exp	e=2.7183....base of natural logarithms
e_a	water vapor pressure, mm of Hg
e_s	saturation water vapor pressure, mm of Hg
F	geometric property defined by equation (6.3)
f_i	i=0, 1, 2,... functional relationship used to shorten equations (6.6) and (6.7)
G_a	air flow rate, kg/m^2s
Gr_C	Grashof number in natural convection mass transfer analysis, dimensionless.
Gr_T	Grashof number in natural convection heat transfer analysis, dimensionless.
g	gravitational aceleration = 9.80665 m/s^2
g_i	i=0, 1, 2,.... functional relationships used to shorten equations (6.6) and (6.7)
H	absolute humidity, dimensionless, decimal
h	convective heat transfer coefficient, $W/m^2°C$
h_d	convective mass transfer coefficient, m/s
h_d'	modified convective mass transfer coefficient, s^{-1}
h_{fg}	latent heat of evaporation, J/kg
K	drying proportionally "constant", hr^{-1}
$\overline{K}'$	drying proportionality "constant" calculated by leaving the density and geometric properties fixed, hr^{-1}
$\overline{K}''$	drying proportionality "constant" calculated by leaving the geometric properties fixed, hr^{-1}

Symbol	
$\bar{K}'''$	drying proportionality "constant" calculated without restriction in the variables, hr^{-1}
L	length of the rectangular bar, cm
L_t	layer thickness, cm
M	average moisture content of a particle, decimal, dry basis
M_a	molecular weight of air, mass units/mole
M_{eq}	equilibrium moisture content, decimal, dry basis (except in equations 5.3 and 5.5 where it is given in percentage, dry basis)
M_o	initial moisture content, decimal, dry basis
M_x	local moisture content at position x, decimal, dry basis
m	mass flux, kg/s
m'	mass flux in units equivalent to energy flux units, W
N	dimensionless number defined by equation (2.23)
N_u	Nusselt Number, dimensionless
n	index n=0, 1, 2, . . .
P	porosity, decimal
Pr	Prandtl Number, dimensionless
p	atmospheric pressure, N/m^2
p_i	i=0, 1, 2, . . . coefficients without physical meaning
q	heat flux, W
q_i	i=0, 1, 2, . . . coefficients without physical meaning
Re	Reynolds number, dimensionless

Symbol	
R_i	incident solar radiation, cal/cm^2hr
R_n	net radiation, W
R_o	universal gas constant = 0.8479 kg m/mole °K
RH	Relative humidity, decimal
R^2	coefficient of determination, dimensionless
r	sphere particle coordinate, m
r_o	sphere radius, m
S	geometric property of rectangular bars given by equation (5.2), cm^{-2}
Sc	Schmidt Number, dimensionless
Sh	Sherwood Number, dimensionless
SS	sum of squares, variable units
T	air dry bulb temperature, ° C
T_a	undisturbed air temperature, °C
T_{abs}	absolute temperature, ° K
T_s	surface temperature. ° C
t	time, s
u	wind velocity, m/s
u_x	velocity component in the x direction, m/s
u_y	velocity component in the direction, m/s
W	thickness of a slab or width of a rectangular bar square section, cm

LIST OF SYMBOLS
(Continued)

Symbol

W_1, W_2	dimensions of the rectangular bar section, cm
X_i	sensitivity coefficients, kg/m^2
x	space coordinate, m
x_i	i=0, 1, 2, ... independent variables, variable units
Y_i	experimental value, variable units
$\overline{Y_i}$	average value of experimental values, variable units
$\widehat{Y_i}$	estimated value, variable units
y	space coordinate, m
α	thermal diffusivity, W/m °C
β	volumetric coefficient of thermal expansion, $°C^{-1}$
β^*	volumetric coefficient of concentration expansion, m^3/kg
γ	kinematic viscosity, m^2/s
Δt	increment in time, hr
δ_c	thickness of the concentration boundary layer, m
δ_T	thickness of the thermal boundary layer, m
δ_u	thickness of the velocity boundary layer, m
ϵ_i	errors, hr^{-1}
ϵ_i'	lack of fit errors, hr^{-1}
ϵ_i''	pure errors, hr^{-1}
θ	product temperature, °C
η	functional relationship, variable units

LIST OF SYMBOLS
(Continued)

Symbol	
ρ_m	fluid density, kg/m^3
ρ_p	product density, kg/m^3
σ^2	variance, hr^{-2}
$\bar{}$	(upper bar) = hourly average value sign.

I INTRODUCTION

Dried cassava is exported from developing countries to the European Economic Community (EEC) for animal feed mixes. Cassava diets are usually considered of equal quality but of lower cost than those based on cereals as the source of carbohydrates. The present annual value of the world-wide cassava transactions is estimated close to one hundred million dollars (Phillips, 1973a) . The demand in the EEC for drier cassava is expected to increase significantly at least until 1980 (phillips, 1973a). Local demand for dry cassava will become more important as knowledge of its value as a feed component becomes known to the local feed manufacturing industries. The crop's characteristics and its hight perishability in the fresh form make it desirable for feeding uses provided that low cost and efficient methods of drying of the product in the field are available.

Exporting countries dry cassava by inefficient, high-risk methods which yields a product that is not always acceptable to the buyers due to the degree of deterioration and poor handling properties by the feed industry's modern equipment. The common drying procedure is to spread irregular pieces of the product on concrete floors or on wooden trays and to stir the product in order to obtain high surface exposure to the solar radiation. This practice results in low capital cost, and ease of the operation. The procedure is an inefficient form of utilizing

the available natural energy to dry cassava.

Literature relevant to this multimillon-dollar industry is scarce, vague, and qualitative, the common denominator being the limited knowledge of the physics involved.

The general objectives of this study are to understand the effect of the important variables affecting the drying process, to use this knowledge in improving the drying efficiency without increasing the costs, to develop and test a mathematical model which describes the process, and to utilize the model for generating useful information. Specific objectives are given in Chapter III.

II REVIEW OF LITERATURE

2.1 Introduction

Cassava is a root which is scarcely known in temperate regions. However, it is a major source of calories for 200 to 300 million people of the tropics (Nestel, 1973a). The plant is known as cassava in English-speaking countries of North America, Europe and Africa; as manioc in French-speaking countries; as tapioca in English-speaking countries of Southeast Asia; as mandioca in Brazil and as yuca in Spanish-speaking countries of South America.

Cassava had remainded an obscure crop until this decade when two major research centers, the International Center for Tropical Agriculture (CIAT) in Colombia and the International Institute for Tropical Agriculture (IITA) in Nigeria started research programs to study basic aspects associated with the production and utilization for this commodity. The first efforts are directed towards determining the actual and future importance of the crop and defining the short and long run research priorities. A major contribution is the preliminary report of a study of the utilization and potential markets of cassava (Phillips, 1973a).

Cassava is a subsistence type of crop for several reasons:

(a) yields are high, (b) it is easy to propagate and grow in poor soils, (c) it has a high drought tolerance, (d) it is an excellent source of carbohydrates, (e) it has a high value per unit area of cultivation, and (f) it is a low risk and non-season bound crop. Cassava production has been restricted in the past because it was considered an inferior, toxic, soil depleting, low value, and high production cost crop. Cassava is produced in more than 80 developing countries. Brazil, Indonesia, Zaire. Nigeria and India produce two thirds of the world production (92.2 million tons were produced in 1970, FAO, 1971).

Average yearly world yield is 9.4 tons/ha. Yields of 70 tons/ha have been obtained under controlled conditions (Nestel, 1973a). Yields of 30 tons/ha can be easily obtained. Yields in terms of calories per unit area and unit time give cassava the first position among all staple food crops (de Vries et al., 1967). Coursey and Haynes (1970) calculated the following figures in thousands of calories per hectarea per day: 250 for cassava, 200 for maize, 176 por rice, 114 for sorghum and 110 for wheat. It is expected that these figures will change in favor of cassava because of the recent technical attention that cassava is receiving and the shortage of carbohydrates in the developing countries (Cock, 1973).

2.2 Utilization of Cassava

2.2.1 Composition

Cassava roots contain approximately 30 to 40 percent dry

matter. About 90 percent of this weight consists of carbohydrates in the form of starch and sugars. Starch makes up about 97 percent of the carbohydrates but when the root reaches and age of 16 to 18 months, the starch content begins to transform rapidly into sugars (Grace, 1971). Cassava starch is classified as a starch of low-amylose and high-amylopectin content.

The protein content of cassava roots is low, usually 0.5 to 1.5 percent. Fats, vitamins and minerals account for even smaller percentages. Amino acid distribution is similar to that of the corn with low levels of methionine. Cassava leaves, however, have protein content values between 21 and 36 percent on a dry weight basis (CIAT, 1973b).

Cassava roots contain linamarin, a cyanogenic glucoside, which can be transformed into hydrocyanic acid by hydrolysis. The amount of the released acid varies from 10 to 150 parts per million, depending on the variety. Sweet and bitter varieties are traditionally classified on these values (CIAT, 1973b).

2.2.2 Cassava as Human Food

The most important use of cassava is human consumption. About 78 to 90 percent of the world production is used for this purpose. Cassava provides approximately 8 to 10 percent of the calories man requires. It is expected that the number of people depending on cassava's energy will double by the end of this century (Nestel, 1973a).

The cassava root is processed by man in a number of different processes:

(a) The root is peeled, then cooked, boiled, baked, or fried similarly to potatoes and finally served as the basic ingredient of certain dishes. (b) The root is peeled, grated, packed in leaves and pressed to extract the juice leaving the pulp. This pulp is the basic constituent of the "farinha de mandioca" or the cassava bread Helmuth, K. B and Scholz, W.(1971) . In the preparation of farinha, the pulp is mixed with fermented pulp and sieved to give a slightly damp meal, which in turn, is evenly heated by turning it continuosly during 3 to 4 hour producing a granular roasted product. Cassava bread is obtained from the pulp in a similar way. The heating is more intensive, without stirring, thus producing a solid brown cake, which is further dried in the sun. The bread is eaten after being dipped in gravy, and can also be stored indefinetely under favorable ambient conditions (Grace, 1971). (c) The grated cassava tubers are fermented, the mass is semi-dextrinized by heat, and finally dried to give a final product known as gari (Grace, 1971). Gari is a very popular food in West Africa and Nigeria. Present mechanized production is accepted by the tradional consumers (Nestel, 1973c).(d) Shredded tubers are pressed in a cloth until most of the juice is squeezed out. The mass is whirled in winnowing baskets until pellets are formed. The pellets are steamed and dried in the sun for several

days to produce cassava rice, a substitute for rice and maize in the Philippines. (e) Cassava roots are boiled and pounded into a very smooth mass which is consumed as a vegetable loaf, like the popular "fufu" in Ghana (Grace, 1971). Instant fufu powder is being commercially produced (Nestel, 1973c). (f) The root is peeled, sliced, dried and pulverized to produce the cassava flour. Cassava flour is used as a substitute for wheat flours in Brasil as well as in some other cassava producing countries. Good progress has been made in the use of cassava flour in bread making (Netel, 1973b). (g) Cassava roots are being used, in experimental trials, as a substrate to produce fungal protein. Progress has been made in this form of utilization (Nestel, 1973b). (h) Cassava is used widely in the food industry in the form of a thickener using the paste properties of starch in soups, baby foods, sauces, puddings and gravies. It is also amployed as a stabilizer for its high water holding capacity.

2.2.3 Cassava in the Non-Food and Feed Industries

Cassava is used in the non-food and feed industries as starch. The low-amylose, high-amylopectin content gives it desirable viscosity (Whiltler and Paschall, 1965) for high quality adhesives, and for use in the paper and textile industries. Grace (1971) gives a detailed list of other industrial uses of cassava starch. The present industial market of cassava, located primarily in the United States, Canada and Japan, accounts only for less than one percent of the total demand for cassava (Phillips, 1973b).

2.3 Cassava in the Feed Industry

The present importance of cassava in the feed industry is due to the demand by the European Economic Community (EEC).

The low digestable protein of cassava is not a constraint in modern feed mixing formulae if cassava is supplemented with high protein sources like the soybean cake meal. Compound feed based on cassava is considered of good quality and less expensive, for favorable tariff reasons, than cereal-based feed formulations (Phillips, 1973a).

Studies at CIAT (CIAT, 1973a) confirmed that when cassava rations are supplemented with methionine, two beneficial results are achieved: (a) the diet is partially balanced, and (b) part of the methionine sulfur converts cyanide to thiocyanate which is excreted in the urine, resulting in the detoxification of the meal. One of the Europe's largest feed compounders seccesfully processed feeds with 60 percent cassava level, showing, that technical constraints do not exist for this industry (Phillips, 1973a).

The demand for dry cassava has increased approximately 300 percent from 1962 to 1971. The 1972 demand for cassava is estimated at 1,700,000 dried tons. The EEC demand for 1980 is expected to increase from 246 to 634 percent with respect to the 1970 demand (Phillips, 1973a). Low and high estimates of the 1980 demand for dried cassava are given in Table 1.

Table 1. Predicated Demand for cassava in the EEC for 1980

(1000 dried metric tons)

Country	Low Estimated	High Estimate
Netherlands	1020	2380
France	157	1950
Denmark	558	1227
W. Germany	677	1161
United Kingdom	472	947
Belgium	472	725
Italy	117	577
TOTAL	3473	8967

Source: Phillips, 1973a

The rise in demand for dry cassava depend upon the following factors: (a) supply, (b) quality, and (c) competitive price.

Quality requirements in particular will increase and result in the following standards, some of them already existing: (a) moisture content less than 14 percent, wet basis (w.b.), (b) starch content greater than 70 or 75 percent, (c) fiber content less than 5 percent, (d) foreign material less than 3 percent, and (e) product efficiency to be handled in pneumatic conveying mechanisms and modern type of handling and storing equipment.

The last requirement is that the product must present a firm mechanical structure to prevent production of fines and powder during the handling process. Traditional cassava chips cause difficulties in pneumatic and small bore auger equipment.

Between 80 and 90 percent of the present world market for cassava is supplied by Thailand and Indonesia. Supply predictions for fresh cassava are given in Table 2. Supply of cassava in Latin America and the Far East substantially exceeds human demand.

Table 2. Predicted Supply of cassava for 1980
(1000 fresh metric tons)

Region	Low Estimate	High Estimate
Latin America	48,052	60,491
Africa	37,107	37,207
Far East	26,357	29,592
TOTAL	111,516	127,290

Source : Phillips, 1973a

It is surprising that no cassava feed market exists in the exporting countries where feeders buy cereals at prices higher than the cost of cassava (Nestel, 1973a) . Instead they prefer to use known technologies instead of investing in the development of new ones appropriate to the country (Johnson, 1970). Price relationships

between presently available feeds and the swine produced are unfavorable to the Colombian cassava producer. Unless feed is produced on the farm, a reasonable return on investment is doubtful (CIAT, 1973a).

The cassava price paid in the EEC had changed from US $65.00 to $78.00 per dry metric ton in the last few years. End-user prices of about $90.00 to $95.00 per dry metric ton are expected for 1980. Production and processing costs should be in the range of $16.00 to $22.00 per ton of fresh root (Phillips, 1973a).

2.4 Storage of Cassava

Ingram and Humphries (1972) made an extensive review of cassava storage in its fresh and dried forms. They concluded that the present knowledge on the subject is vague and that few reliable data exist. The only tested methods for safe storing cassava for periods exceeding two months are : (a) freezing the root, (b) drying the roots to a moisture content of 13 percent and keep up it to this level at ambient temperatures, (c) leaving the roots in the ground until 16 or 18 months for age.

Cassava tuber severely rot at ambient temperatures within a few days after being harvested. The rotting starts as vascular streaking at the surfaces at a rate proportionally to the mechanical damage of the root when harvested (CIAT, 1973a).

Two promising methods of extending the shelf-life of the fresh product have been investigated: (a) experiments with paraffin

wax dips (Young et al., 1971) and (b) storing the roots piled in the ground in a structure resembling the European potato "clamp". Roots have been stored by this method for five weeks without deterioration. The success of "clamping" in preventing deterioration suggests that either the conditions within the clamp (temperatures above 38°C and relative humidities above 90 percent) prevent the invasion of wounds or that the wounds heal preventing deterioration (CIAT, 1973a).

Dried chips with moisture contents equal to or less than 13 percent, wet basis (w.b.), can be stored for more than one year without molding. At higher moisture content values, the product is susceptible to molding at rates proportional to the moisture content. No quantification of molding versus moisture content, time, air temperature and air relative humidity has been published.

At least fifteen different insects attack dried chips (Ingram and Humphries, 1972). The use of chemicals, like methyl bromide, ethylene dibromide and the mixture of ethylene dichloride has given complete control of infestations (Pingale et al., 1956; Anon., 1962).

2.5 Drying of Cassava

Cassava pellets and chips are the common forms of using cassava in the feed industry. Chips are produced in Thailand and Indonesia by mechanical slicing of cassava followed by natural drying of the product in layers on concrete floors or wooden trays. In Brazil (Helmuth, K. B. and Scholz, W., 1971) cassava slices are

pressed to reduce significantly their moisture content prior to drying them in continuos type of driers. The product is pulverized in hammer mills resulting in cassava flour. Washing and trimming before these processes are done by hand or by inexpensive machinery. Pellets are produced from the cassava flour in special machinery (Helmuth, and Scholz (1971).

Several types of cassava cutters have been designed (Hachero, 1951; Gill, 1972; Grace, 1971; Lavigne, 1966), but the desirable drying and handling properties are not specified. The most widely accepted machine consists of a rotating, notched cutting disc which produces non-uniform, thin slides of high surface to volume ratio. The slices present a weak structure because bending forces during cutting and releasing of the particles produce internal shearing strains. This product is fragile when wet and dusty when dry.

Generally recommended drying procedures are: (a) the product should be spread in the sun on concrete floors of wooden trays as soon as it is cut, (b) the layer density should not exceed 5 to 15 kg/m^2, (c) the chips should be turned periodically during drying, (d) if rain threatens, the chips should be piled up under a roof or covered with sheets. In good sunshine the drying period is usually 2 to 5 days (Grace, 1971; Kuppuswamy, 1962; Lavigne, 1966). No critical desorption rates related to quality deterioration have been

reported.

Lavigne (1966) concluded in his study of natural drying of cassava, that if drying trays were loaded with 10 to 15 kg/m^2 and stirred every day, it would take 70 sun-hours to dry the product. Onn (1972) conducted a number of experimental drying studies with cassava chips using air heated by collected solar radiation and blowing the air through the layer with the aid of a fan. He encoutered aerodynamic problems with the non-uniform air circulation through the layers of chips and concluded that drying of thick layers with solar heated air was not feasible. Gill (1972) dried cassava chips on a tray by heating ambient air artificially and forcing it through the layer by a fan. The data obtained was discussed with respect to average drying of different bed depths. No recomendation were made regarding optimum air flow-temperature relationships for the different tray loads. Gill also encountered poor air flow distributions. Chirife and Cachero (1970) and Chirife (1971) analyzed the forced, high temperature air drying of cassava layers of different dephts. The data was analyzed by using moisture diffusion equations valid only for thin layers of cassava fully exposed to the air.

2.6 Tray Drying

High moisture content products like vegetables, roots, fruits, as well as many chemical products of rather difficult drying

charactheristics, are dried commercially in layers. Modern tray driers consist of insulated cabinets with integral centrifugal fans and heating coils. Perforated trays with a surface area between 0.3 to 1.0 m^2 are commonly loaded in uniform layers from 5 to 15 kg/m^2 to a depth of 0.1 to 1.0 m (Keey, 1972). Air velocities between 1 and 10 m/sec are maintained over the surfaces. The driers are designed to assure uniform air circulation. In more sophisticated designs, the air is forced through the layers. Higher tray loads can be processed with this type of drier (Keey, 1972).

Van Arsdel (1963) presented the status of research on tray-drying of vegetables and roots. The study consists of a discussion of the drying characteristics of isolated laboratory experiments, and a study of a commercial operation.

In Van Arsdel's report all variables of importance were fixed, except the one being tested. The specific variables studied were: (a) kind of the product, (b) cross section of the product cut in rectangular bars, (c) initial load per unit area (density), (d) air temperature at constant wet bulb depression, i.e., variation in dry and wet bulb temperature leaving the temperature difference constant, and (e) air velocity.

Results of the analysis with carrots and potatoes indicated that (a) carrot drying rates per unit dry matter content were higher than those of potatoes because of the carrot's higher initial moisture

content, (b) the smallest particle tested, a rectangular bar of 0.3x0.4 cm in section, was the most efficient to dry. Air at 70°C and at 4m/sec was forced over the particles. The tray density (initial load of the fresh product per unit area) was 7.4 kg/m^2, (c) drying rates reduced materially when the tray densities were increased, the differences being higher at the early drying stages, (d) drying at the begining of the process -- drying in the constant-rate drying period -- were correlated to the wet-bulb temperature depression and to the air velocity, (e) drying rates of potato half-dice were shown to be not effected by increasing the air velocities beyond 3m/sec. Air temperatures was kept at 70° C. The tray density was 7.4 kg/m^2.

2.7 Drying Theory

Mathematical modeling of drying of biological products is a subject of increasing interest in many research institutions. The first successful attempt was reported by Sherwood (1929), who theorized that molecular diffusion of water in the liquid or vapor states was the drying force that makes the mass of water flow through the porous structure of the particle. Mathemetical models which describe the physics of the phenomena are highly desirable because many applications can be obtained quantitatively from a reliable model.

2.7.1 Thin Layer Drying

In developing models for any drying configuration it has been

generally accepted that it is first necessary to describe the drying behevior of the single particle of which the system is made. The unsteady state theory for a one dimensional slab is expressed by the second partial differential equation

$$\frac{\partial M_x}{\partial t} = \frac{\partial}{\partial x}\left(D_e \frac{\partial M_x}{\partial x} \right) \qquad (2.1)$$

where M_x is the local moisture content inside the particle. The position (x) and the process time (t) are the independent variables. The diffusion coefficient (D_e) is, in general, a function of the moisture content and the product temperature.

The internal gradient is caused by a lower moisture content at the product surface than at the interior of the drying particle. The moisture driven force at the surface is given by the difference between the vapor pressure at the particle surface and the vapor concentration of the surrounding air. The functional relationship is approximated by the boundary condition for aquation (2.1) :

$$D_e \frac{\partial M_x}{\partial x}\bigg|_{x=W} = - h_d(M_{x=W} - M_{eq}) \qquad (2.2)$$

M_{eq} is the equilibrium moisture content of the product at the air condictions, h_d the convective mass transfer coefficient, and W the thickness of the slab. When the initial moisture content is given, the model is complete in its differential form. Integration in varying

conditions and non-constant product properties is only possible by transforming the formulation to a finite-difference form and using a numerical method with the aid of a computer. If the initial moisture content is assumed uniform, the diffusion coefficient a constant, fixed boundary conditions ($M_{x=W} = M_{eq}$) and no shrinkage, the analytical integration gives (Crank, 1956)

$$\frac{M - M_{eq}}{M_o - M_{eq}} \quad \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[- \frac{(2n+1)^2 \pi^2 D_e t}{4W^2} \right] \tag{2.3}$$

where M is the average moisture content of the slab. The left-hand term is the moisture ratio, a normalized moisture variable with unique advantages in representing drying processes. The moisture ratio represents physically that portion of water which remains in the particle, at a given time (t), but that could be evaporated totally by just giveng sufficient time to complete the diffusion process at the same air conditions. The right-hand term depends on the physical properties of the product and process time.

If the term $(\pi^2 D_e t/4W^2)$ is greather than 1.2 the second and following terms of the sum can be neglected without appreciable error (Pabis and Henderson, 1961). The solution takes the form

$$\frac{M - M_{eq}}{M_o - M_{eq}} = \frac{8}{\pi^2} \exp\left(- \frac{\pi^2 D_e t}{4W^2} \right) \tag{2.4}$$

With generalization under the same approximate conditions the diffusional process in a rectangular bar can be expressed by the equation (Pabis and Henderson, 1961)

$$\frac{M - M_{eq}}{M_o - M_{eq}} = \frac{512}{\pi^6} \exp\left[- \frac{\pi^2 D_e t}{4} \left(\frac{1}{L^2} + \frac{1}{W_1^2} + \frac{1}{W_2^2} \right) \right] \quad (2.5)$$

where L, W_1, W_2, the dimensions of the bar, are assumed to be constant. In real conditions they change their lengths due to plastic deformation that take place to some extent during drying (shrinkage phenomenon). The shrinkage of the linear dimension of the piece is approximately a linear function of the moisture content (Van Arsdel, 1963).

If the boundary conditions are of the more general form of equation (2.2) the analytical solution of equation (2.1) consists of infinite sum of trigonometric terms which are usually expressed in graphical forms (Heisler Charts) and is presented in standard texts of heat transfer (Kreith, 1973). The disadvantages of this solution are (a) its complexity and time-consuming to use (Beck, 1972), and (b) the non-availability of the diffusion coefficient function for most crops.

Investigators have been forced to accept semi-empirical or empirical types of thin layer formulations which have provided approximate results for selected ranges of the variables of interest.

The most widely used equation is

$$\frac{dM}{dt} = - K (M - M_{eq}) \tag{2.6}$$

with solution

$$\frac{M - M_{eq}}{M_o - M_{eq}} = \exp (- Kt) \tag{2.7}$$

K is known as the drying proportionality constant. Several functional relationships had been given for K, but no agreement exists between them (Henderson and Pabis, 1961; Morey and Peart, 1971; Kemp et al., 1972; Midden at al., 1973). The most commonly form accepted for K is

$$K = d_1 \exp (-\frac{d_2}{T_{abs}}) \tag{2.8}$$

Equation (2.8) is known as the Arrhenius function for the diffusion coefficient. The constants d_1 and d_2 are estimated to fit the experimental data for each particular product. Equation (2.8) does not contain a moisture flow potential function.

Experimental data of thin layer drying reveal, sometimes, two differences with respect to the theoretical analysis presented above, see Figure 1. They are : (a) there may exist a period in which the drying rate remains constant. Constant drying rates are caused by the presence of free water on the particle surfaces at the

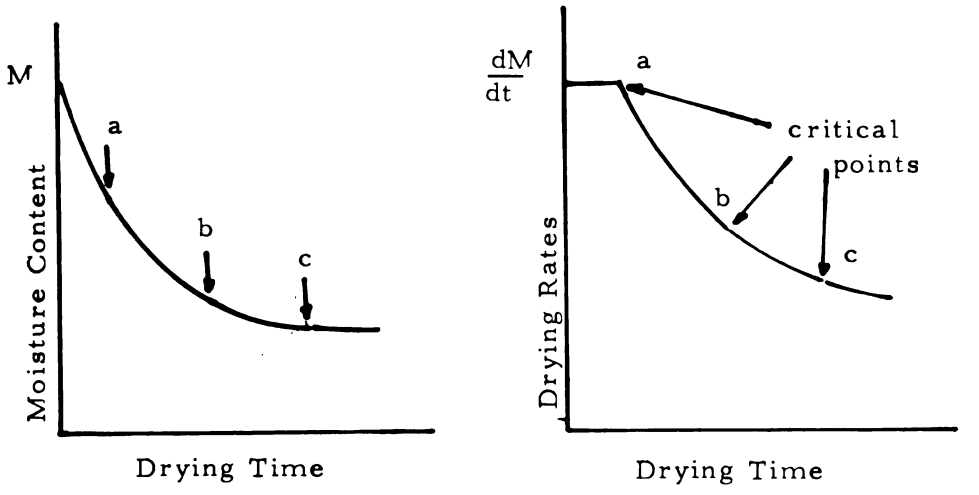


Figure 1. Experimental Thin Layer Drying Curves

beginning of the process. The length of the constant drying depends on the kind of product, its initial moisture content and the drying capacity of the air. The estimation of the moisture losses in this period is treated by convection theory (Villa, 1973), (b) the drying rates during the diffusional process that follows the constant drying period -- also called the falling drying period -- might not be a smooth falling function but present some discontinuities -- critical points -- . The critical points divide the curve in two, three or more falling drying periods, Hall (1957). No general explanations have been given of this phenomena.

The modeling of drying systems becomes more complicated when the moisture removed from one particle affects the state of the air surrounding other adjacent particles by reducing the saturation

vapor pressure deficit. This is, however, the practical situation in drying biological products in layers or in the deep beds of commercial driers. This problem is a complex interaction of momentum, heat and mass transfer.

2.7.2 Deep Bed Drying

Only very recently rigorous heat and mass balances have been written and solved to model commercial driers (Bakker - Arkema and Brooker, 1970). The alternative of empirical models has also been used (Thompson, 1970).

The Michigan State Drying Model for a stationary bed of grain is described below (Bakker-Arkema et al., 1974). The following assumptions are made: (a) the bed does not reduce its original volume due to shrinkage, (b) the single particle does not present temperature gradients, (c) heat is not transfered by conduction from one particle to another, (d) the air flow is uniform through all sections of the bed, (e) the drier walls act like a perfect thermal insulator, (f) gradients of temperature and humidity with respect to time are small compared with the gradients of the same variables with respect to position. A sketch of the drier is given in Figure 2.

A differential volume (A.dx) is chosen in an arbitrary position of the bed. Heat and mass transfer balances are written for the air and product in the general form:

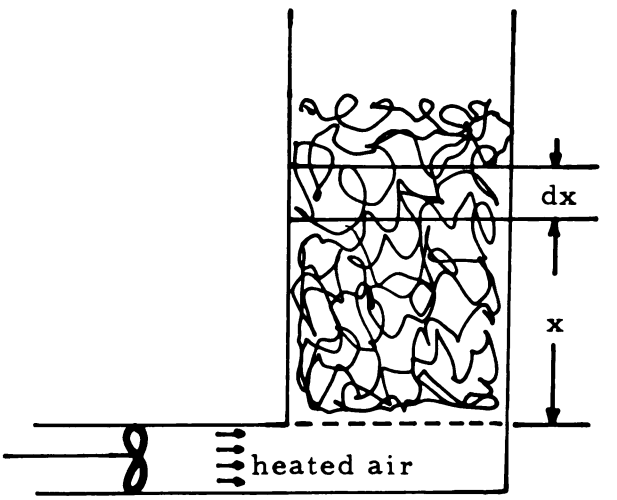


Figure 2. Stationary Deep Bed Drier.

$\begin{bmatrix}\text{energy}\\ \text{mass}\end{bmatrix}$ entering at x minus $\begin{bmatrix}\text{energy}\\ \text{mass}\end{bmatrix}$ leaving at x+dx equal to

$\begin{bmatrix}\text{energy}\\ \text{mass}\end{bmatrix}$ of evaporation plus change in the product internal $\begin{bmatrix}\text{energy}\\ \text{mass}\end{bmatrix}$

The system of the simultaneous equations after simplifying terms is presented below with the diffusion equation of the single particle, which completes the needed number of equations to solve for the unknowns.

$$\frac{\partial T}{\partial x} = -\frac{hA\,(T - \Theta)}{G_a c_a + G_a c_v H} \tag{2.9}$$

$$\frac{\partial \Theta}{\partial t} = \frac{h A (T - \Theta)}{\rho_p c_p + \rho_p c_w M_r} - \frac{h_{fg} + c_v (T - \Theta)}{c_p + c_w M_r} \frac{\partial M_r}{\partial t} \tag{2.10}$$

$$\frac{\partial H}{\partial x} = - \frac{\rho_p}{G_a} \frac{\partial M_r}{\partial t} \tag{2.11}$$

$$\frac{\partial M}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 D_e \frac{\partial M_r}{\partial r} \right) \tag{2.12}$$

$$M = \frac{3}{r_o^3} \int_0^{r_o} M_r \, r^2 \, dr \tag{2.13}$$

Equations (12) and (13) represent the diffusion of water in a single particle which is assumed to be a sphere. In practical simulation studies they can be replaced by an equivalent empirical thin layer equation.

The boundary and initial conditions needed to solve the system are:

$$T(x, 0) = T_{initial} \qquad T(0, t) = T_{inlet}$$

$$H(x, 0) = H_{initial} \qquad H(0, t) = H_{inlet}$$

$$\Theta(x, 0) = \Theta_{initial} \qquad M(x, r, 0) = M_{initial}$$

$$D_e \left. \frac{\partial M}{\partial r} \right|_{r = r_o} = -h_d (M_{r=r_o} - M_{eq}) \tag{2.14}$$

where T is the air temperature, h is the convective heat transfer coefficient, A the product surface area, θ the product temperature, G_a the air flow rate, c_a the dry air specific heat, c_v the water vapor specific air, H the air absoluts humidity, ρ_p the dry product density, c_p the dry product specific heat, c_w the water specific heat, M the average moisture content of the particle, h_{fg} the latent heat of vaporization, M_r the local moisture content inside the particle, r the space dimension inside the perticle, r_o the radius of the sphere.

The hygroscopic data represented by M_{eq} is given for each product as a function of the air temperature and relative humidity by a functional relationship. The system is solved with the aid of high a speed computer after replacing the differential forms into algebraic equations by using standard finite-difference methods. The solution is the values of the five unknowns T, θ, H, M_r, and M for each point of the bed and for any time during the drier operation. Comparison of calculated and experimental data has given good results when the settling of the bed was negligible and the air flow uniform (Bakker-Arkema et al., 1974).

The model developed and tested, has many practical applications including: (a) construction of simple nomograms to specify drying procedures for certified Red Kidney Bean seed (Bakker- Arkema et al., 1971), (b) use of the model in conjuction

with sensitivity analysis to recommend optimum design parameters as function of ambient and economic considerations for a given geographical area (Farmer and Bakker-Arkema, 1971), (c) the stationary model in modified form to describe the three most common types of continuous driers: concurrent, contercurrent and croos flow. By using the cross flow model it was possible to explain the high efficiency of the popular Hart-Carter commercial drier and suggest forms of improving it (Lerew et al., 1972).

2.7.3 Natural Drying

Evaporation rates from surfaces of the cassava paticles drying in thick layers under variable atmospheric conditions -- with solar radiation effects neglected -- depend (a) on the diffusion process of the water inside particles as was discussed at the begining of this section, and (b) on the flow characteristics and properties of the air surrounding the particle surfaces. Any of these two physical processes, or both, can be the controlling mechanisms in natural drying. The latter phenomenon constitutes a simultaneous process of momentum and convective heat and mass transfer.

The rates of heat and mass exhange between a given surface and the surrounding moist air are given by the general convective heat and mass transfer equations, respectively:

$$q = h A (T_s - T_a) \qquad (2.15)$$

$$m = h_d A (C_s - C_a) \qquad (2.16)$$

where q is the heat flux, h the convective heat transfer coefficient, m the mass flux, T_s the surface temperature, T the undisturbed air temperature, C_s the concentration of the water vapor at the surface, C_a the water vapor concentration of the undisturbed air.

The temperature, concentration and velocity profiles (T, C, u) within the thin film of air adjacent to a surface (boundary layer) are schematically shown in Figure 3, where moist air moves upwards in fully developed laminar flow over a vertical, porous flat plate. The boundary layer dimensions δ_C, δ_u, δ_T are the thicknesses of the thin layers, i.e., the maximum distances from the wall in which gradients of concentration, velocity and temperature are present.

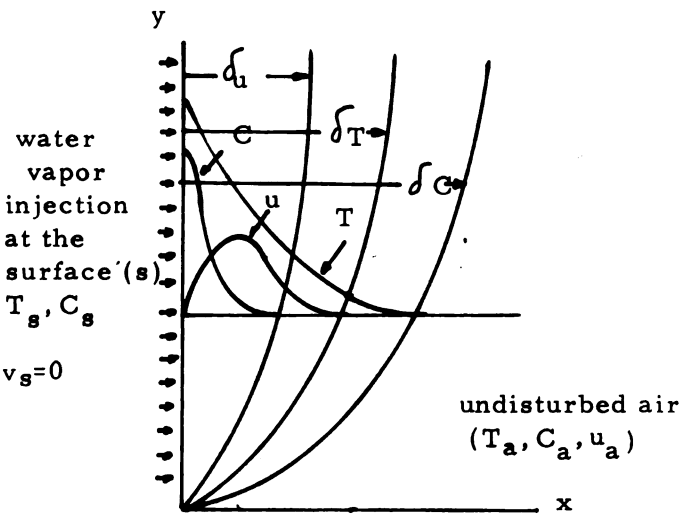


Figure 3. Boundary Layer in Natural Convection

The air moves upwards due to bouyancy forces caused by the heating and the water vapor injected from the porous surface. Fluid jets and plumes also create buoyancy forces in the atmosphere. These processes are treated similarly by natural convection theory (Gebhart, 1973).

The main objective of the analytical of convection problems over surfaces is to find mathematical expressions for the convective coefficients h and h_d. When they are obtained, the heat and mass transfer problem is essentially solved. Analytical expressions for the convective coefficients are obtained by equating the expressions (2.16) and (2.17) to other heat and mass transfer expressions which require the knowledge of the exact distribution of temperature and concentration within the boundary layer (Rohsenow and Choi, 1961). The temperature and concentration distributions are obtained by solving the simultaneous momentum, heat, and mass transfer differential equations with appropriate boundary conditions. The boundary layer solution might be very difficult, if not impossible, to obtain for practical problems. One alternative is to utilize the known governing differential equations of the boundary layer problem to derive empirical formulations consisting of dimensionless numbers and unknown parameters. The parameters are estimated from the experimental data.

Natural convection of fluids moving over surfaces or in free spaces are of great importance in many areas of science. Today, natural

diffusion of gases and liquids in the atmosphere and water reservoirs, respectively, is a topic of concern. Protection of hot surfaces by evaporative cooling, condensation of water vapor, humidification and dehumidification of air, heating of buildings, evaporation from lakes, rivers, and irrigation channels, evapotranspiration, and many industrial processes, like drying, are additional examples fo the applications of natural convection.

Gebhart and Pera (1971) reviewed relevant work on natural convection flows resulting from combined buoyancy effects of thermal and mass diffusion. Gebhart (1973) also reviewed the general topic of natural convection. The problem of combined buoyancy effects has received little attention in spite of the fact that flows in nature, at all scales, result to a significant extent from simultaneous thermal and concentration gradients. Gill et al. (1965) solved, after some simplifications, the boundary value problem ilustrated in figure 3, i.e., the steady and laminar flow over a vertical porous wall. Bouyancy forces were originated by heating and injection of water vapor from the surface. This study revealed that at very low water injection rates the heat transfer increases, but at high concentration values the rates decreased markedly because of the thickening of the boundary layer and because of the lower thermal diffusivity of the moist air compared to that of dry air. Sparrow et al. (1966) corroborated this finding by an experimental and analytical investigation of

natural convection around a horizontal cylinder. The boundary layer was created by injection of steam through a porous cylinder located in still air. The analysis was in good agreement with the experimental results for low mass injection. At higher concentrations, the mass rates predicted by the model fell about 25 percent below the experimental data. The difference was attributed to the turbulent flow created by the water vapor injections.

Gebhart and Pera (1971) solved the simultaneous, steady, momentum, heat and mass transfer equations (written below) for a two dimensional steady flow of an incompresible fluid with constant properties. Concentration differences were assumed very small, as it is the case in many flows in the atmosphere. Additional momentum and energy fluxes due to mass transfer and viscous dissipation were considered negligible. The simplified equations are:

continuity:

$$\frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} = 0 \tag{2.17}$$

momentum balance:

$$u_x \frac{\partial u_y}{\partial x} + u_y \frac{\partial u_y}{\partial y} = \gamma \frac{\partial^2 u_x}{\partial y^2} + g\beta (T - T_a) + g\beta^* (C - C_a) \tag{2.18}$$

heat transfer balance:

$$u_x \frac{\partial T}{\partial x} + u_y \frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} \qquad (2.19)$$

mass transfer balance:

$$u_x \frac{\partial C}{\partial x} + u_y \frac{\partial C}{\partial y} = D_e \frac{\partial^2 C}{\partial y^2} \qquad (2.20)$$

where u_x is the velocity component in the x direction, u_y the velocity in the y direction, γ the kinematic viscosity of the fluid, T the air temperature in the boundary layer, T_a the air temperature in the undisturbed air, g the gravitional aceleration, β the volumetric coefficient of thermal expansion given the by the expression

$$\beta = - \frac{1}{\rho_m} \left(\frac{\partial \rho_m}{\partial T} \right)_{p,C} \qquad (2.21)$$

where ρ_m is the fluid density, p the fluid pressure, β^* the volumetric coefficient of expansion with concentration given by the expression

$$\beta^* = - \frac{1}{\rho_m} \left(\frac{\partial \rho_m}{\partial C} \right)_{p,T} \qquad (2.22)$$

and α is the thermal diffusivity of the fluid.

The system of equations was integrated for different boundary conditions. The importance of the two buoyancy forces $g\beta(T-T_a)$ and $g\beta^*(C-C_a)$ of equation (2.19) was studied by varying the N number defined as

$$N = \frac{\beta^{*}(C - C_a)}{\beta (T - T_a)} \qquad (2.23)$$

The solution of the system, i.e., the velocity, temperature, and concentration distributions within the boundary layer, were shown to be functions of the Grashof numbers:

$$Gr_{x,T} = \frac{g\beta x^3 (T_s - T_a)}{\gamma^2}; Gr_{x,C} = \frac{g\beta^{*} x^3 (C_s - C_a)}{\gamma^2} \qquad (2.24)$$

note also

$$N = \frac{Gr_{x,C}}{Gr_{x,T}} \qquad (2.23)$$

The buoyancy forces due to concentration gradients were shown to be of importance for atmospheric conditions. For example, N can take the value of 3 for air at 20° C. N is zero for no thermal diffusion, positive for both effects aiding to drive the flow, and negative for opposed effects. The Prandtl (Pr) and Schmidt (Sc) numbers:

$$Pr = \frac{\gamma}{\alpha} \quad ; \quad Sc = \frac{\gamma}{D_e} \qquad (2.25)$$

were varied in this study for air at atmospheric conditions (Pr=0.7 and Sc=0.1 to 10). The study also considered the interactions between the air velocity and the rates of heat and mass transfer.

If the diffusion equation is neglected, the solution of the system of equations (2.17) to (2.20) is given, approximately, by the empirical equation (Rohsenow and Choi, 1961)

$$\frac{Nu_x}{(0.25Gr_{x,T})^{0.25}} = \frac{0.676\ Pr^{0.5}}{(0.861+Pr)^{0.25}} \tag{2.26}$$

where Nu is the Nusselt number

$$Nu_x = \frac{h\ x}{k} \tag{2.27}$$

Equation (2.26) is also the solution of the boundary layer system for neglegible thermal effects. For this case the Grashof numbers are interchanged, the Schmidt number replaces the Prandtl number and the Nusselt number is replaced by the Sherwood (Sh) number, where

$$Sh_x = \frac{h_d\ x}{D_e} \tag{2.28}$$

Forced convection results when the buoyancy forces are small compared with external forces applied to the fluid in the boundary layer. The system of equations (2.17) to (2.21) becomes simpler to solve (Rohsenow and Choi, 1961). The solution for the dependent variables are given as function of the Prandtl, Schmidt, and Reynolds (Re) number, where

$$Re_x = \frac{u_x x}{\nu} \tag{2.29}$$

Lamimar flows are usually followed by turbulent flow. Turbulence is created by the roughness of the surfaces, high Reynolds numbers, instability of the fluid, duration of the process, etc. The analytical treatment of turbulent flows is not as well developed as it is for laminar flows. The knowledge gained from the laminar flow solutions is utilized to design empirical formulations consisting of dimensionless numbers with unknown parameters. The parameters are estimated from the experimental data. Good correlation was obtained , for example, between experimental data on evaporation of liquids in a wetted wall column (Rohsenow and Choi, 1961) with the following empirical equation

$$Sh = 0.023\,(Re)^{0.83}\,(Sc)^{0.44} \tag{2.30}$$

The Reynolds and Colburn analogies (Rohsenow and Choi, 1961) can be utilized to estimate mass transfer coefficients as a function of the corresponding heat transfer coefficients. The use of the transfer analogies is voided for low rates mass transfer, i.e. when the velocity profile is not affected by the mass transfer (Welty et al. 1969).

Most natural convective processes found in nature occur on a large scale and are of such long duration that the transport mechanism

is largely turbulent (Gebhart, 1973). The flow characteristics vary from laminar flow, stable stratified fluid, unstable laminar flow, transition flow, to newly developed turbulent flow (Gebhert, 1973).

Nonsteady state behavior of the flows complicates the analysis even more. Transient boundary layer problems have been solved by numerical integration for conditions of particular interest. The results have not been found to be of general application (Gebhart, 1973).

The nature of the fluid flow over cassava particles drying in horizontal or vertical layers under atmospheric conditions can be generally described as boundary layer flow with the following characteristics : (a) three dimensional, unsteady state, with water vapor injection from the surfaces; (b) natural or forced flow influenced by unpredictable air flow characteristics; (c) laminar, in transition, or turbulent flow. The magnitude and direction of the air will determine the nature of the flow over the surfaces. External and internal particles of the layer are subjected, simultaneously, to different flows as result of the resistance presented by the layer (static pressure) to the air flow. At high wind speed and appropiate wind direction the air can be forced through the thick layer. In this limiting case, the system of equations (2.9) to (2.14) applies to the natural drying problem. In conclusion, the complex natural drying phenomenon can not be analyzed theoretically with the present state

of knowledge. Consideration of the solar radiation effects for products with not neglegible solar absorptivity, result in a substantial complication.

Most of the reported efforts on natural drying have been directed to improve the efficiency of collecting the solar radiation and to utilize the solar heated air to dry the moist product. The methods proposed are in some form similar to the solar stills. Good knowledge exists of the heat transfer process that occurs in collectors made of selected surfaces, covered by glass or plastic sheets transparent to the high frequency solar radiation but opaque to the low frequency radiant energy emitted by the heated surfaces (Buelow, 1956; Whillier, 1964; Malik and Van-Vi Tran, 1970; Satcunathan and Deonarine, 1971).

Solar cabinets have been designed in several forms. The collectors have been selected surfaces, the product itself or a combination of both. The product position has been varied inside the cabinet. The released moisture escapes the cabinet by diffusion, natural convection, condensed water, or with the aid of a fan naturally powered by the wind (Ismailova, 1957; Khan, 1964; Lawand, 1966; Nahlawi, 1966: Headley and Springer, 1973). Although the cabinets have been more efficient than drying the product naturally on horizontal surfaces, the maximum drying rates reported for yams are 2.8 kg/m^2 of water removed in 20 hrs (Headley and Springer, 1973) and 1.2 kg/m^2 in 24 hrs (Nahlawi, 1966).

Wilson (1961) found that in drying grapes in Australia, the combined effect of solar radiation and natural air circulations was more effective and less expensive that the use of solar collectors or supplementary heat.

In summary, the applied natural drying literature is scarce, qualitative and imprecise. Mathematical modeling of the process has been considered a difficult subject because of the uncontrolled variability of the environment and the slow response of the product to the environmental changes.

On the other hand, some models have been developed under controlled conditions but not tested in the field. Kemp et al.,(1972) attempted to incorporate a single evaporation variable into an empirical drying equation for hay :

$$\frac{M - M_{eq}}{M_o - M_{eq}} = \exp\left[- d_3 (h_{fg}) (t)^{d_4} \right] \qquad (2.31)$$

where d_3 and d_4 are constants estimated from the experimental data, h_{fg} is the latent heat of evaporation.

2.7.4 Evaporation

Mathematical modeling of evaporation from free water surfaces, soils and vegetated fields (evapotranspiration) has been a challenging research subject in engineering. Scientific interest in

the physics of evaporation dates back to Aristotle (384-322B.C.) who stated that "wind is more essential in evaporation that the sun".

Evaporation was considered in section (2.7.2) as a coupled phenomena of momentum, heat, and mass transfer which occur simultaneously in the boundary layer. Natural or forced convection drive the moisture to the atmosphere. The system of equations (2.17) to (2.20) applies to the two dimensional, natural evaporation case. The solar radiation absorved by the water surface should be considered in applying the boundary conditions in the analytical solution of the system. Solution to the boundary layer problem is not used in practical estimations because its complexity and the need to estimate evaporation rates from large, non-homogeneous surfaces. Empirical formulations are extensively used instead.

Equation (2.16) can be transformed into an empirical equation by assuming that the moist air surrounding the surface is an ideal gas with a temperature equal to the temperature of the water surface. The resulting equation is

$$\frac{m}{A} = h_d' (e_s - e_a) \qquad (2.32)$$

where $h_d' = h_d M_a / R_o T_{abs}$, M_a is the molecular weight of the moist air, R_o the universal gas constant. Equation (2.32) was first suggested by Dalton (17th century, A.D.)

A linear function of the wind velocity has been proposed to

account for the air velocity effect on the modified convective mass transfer coefficient (h'_d)

$$\frac{m}{A} = (d_4 + d_5 u)\ (e_s - e_a) \tag{2.33}$$

where d_4 and d_5 are constants estimated from the experimental data. No consistency has been found for these constants (Slatyer, 1967).

Penman (1948) derived the most commonly used evaporation equation. It is based on a simplified energy balance aided with an empirical function

$$\frac{m'}{A} \quad \frac{R_n \frac{\partial e_s}{\partial T} + (d_6 + d_7 u)\ (e_s - e_a)}{\frac{\partial e_s}{\partial T} + 0.27} \tag{2.34}$$

R_n is the net solar radiation; $\frac{\partial e_s}{\partial T}$ is the slope of the saturation curve evaluated at the dry bulb temperature of the air, d_6 and d_7 are constants ; m' is the mass flux in energy flux units.

Equation (2.34) is commonly modified in estimating rates of evapotranspiration from different canopies (Slatyer, 1967). The effect of the total incident solar radiation on evaporation can be very small compared with the energy supplied by the air, even in good sunny days. Lemon et al. (1957) ilustrated this phenomena by

measuremets made in an irrigated cotton crop. The ratio of the air enthalpy given off to the net radiation was 1.5.

The microclimatology budget of a region can be altered substantially by changing the solar absorptance characteristics of the floor surfaces. Aderinkhing (1951) made observations, during three years, of the air temperature at 50 cm above three different types of surfaces : (a) natural soil, (b) artificially darkened, and (c) artificially lightened. On windless days he observed temperature differences of 3 to 5°C over the dark and light surfaces and 2 to 3 degrees over the dark and natural surfaces.

It was expected that the natural drying of cassava could be explained by the present theories on drying, evaporation and solar absorption.

III OBJETIVES

The objetives of this study were:

A. To develop a mathematical model capable of accurately simulating different systems of natural drying of cassava layers in arbitrarily chosen environmental conditions.

B. To utilize the model to (a) compare the physical efficiencies of several natural drying systems, including the traditional methods of drying cassava on concrete floors of wooden trays (the drying systems differ one from the other in the relative position of the layer with respect to the floor, or in the form of the cassava particles), (b) recomend maximum loading of the cassava layers to be dried without significant quality deterioration as a function of the first-day ambient conditions, and the drying system, (c) study the influence of changing the important independent variables on the changes of the maximum layer loads, and (d) estimate the relative economic efficiency of commercial operations of three natural drying systems.

C. To design (a) low - cost cutting machinery to produce cassava particles suitable for drying efficientely, and (b) inexpensive drying systems with higher drying efficiencies than conventional systems.

IV EXPERIMENTAL PROCEDURES AND PRELIMINARY ANALYSIS

Extensive experimental work was performed during the study because (a) the available information did not provide effective gides to concentrate the efforts in one specific field on natural drying, (b) a large number of non-controlled independent variables were important in the process, and (c) the analysis of the preliminary results suggested new and more efficient forms of natural drying.

The independent information on drying, evaporation and solar collectors provided guidelines to design the first scaled experiments. The sequence of analyzing preliminary results and improving the drying system was repeated until a prototype of a commercial drier system with obvious advantages over the other drying forms was built and tested.

The description of the experiments follow their chronological sequence.

4.1 Importance of Differences of the Cassava Porous Structure in Drying

The first drying experiments were performed on August 31, September 1, and September 2, 1972 (See Table 3 for average weather conditions and Appendix B for the detailed experimental data)

Table 3. Average Ambient Conditions During Experimental Hours.

Day	Hours	Temp.	Rel.Hum.	Wind Vel.	Radiation
	hr	°C	%	m/sec	cal/cm^2-hr
Aug 31,72	5	31.3	49.6	1.09	61.0
Sep. 1	9	29.4	55.3	0.62	40.7
Sep. 2	4	28.2	66.8	0.62	53.3
Sep.14	7	33.0	47.3	1.87	45.2
Sep.21	8	30.9	54.3	0.81	53.2
Sep.29	6	34.2	44.3	1.60	51.4
Oct 5	6	32.9	46.8	1.90	56.0
Oct 17	6	34.0	38.9	0.90	49.5
Oct.27	6	34.1	41.4	1.47	45.4
Mar 7, 73	5	28.6	57.9	0.92	-
Mar 8	9	29.9	54.9	1.45	-
Mar10	4	29.1	53.4	3.67	27.2
Mar 11	3	26.8	67.0	0.78	30.1
Mar 14	5	33.1	46.9	2.40	47.8
Mar 15	9	30.4	52.5	1.75	43.2
Mar 21	6	32.8	41.4	2.34	39.8
Mar 22	9	31.5	47.5	1.93	41.2
Mar 24	7	30.4	58.7	2.71	37.9
Mar 25	5	28.5	56.2	0.91	41.5
Mar 28	6	31.8	47.5	2.99	36.0
Mar 29	9	29.7	54.6	0.91	29.5
Mar 31	6	31.9	49.8	2.28	29.3
Apr 1	5	27.5	65.2	0.97	53.8
Apr 4	5	32.8	40.9	2.20	31.3
Apr 5	9	27.1	59.7	1.80	31.2
Apr 7	5	27.1	63.1	1.96	31.2
Apr 8	4	28.3	58.8	0.59	46.2
Apr 11	7	28.4	50.5	1.61	35.9
Apr 12	8	28.6	49.1	1.39	47.5
Apr 14	6	31.8	41.1	2.16	36.6
Apr 15	5	26.7	54.0	0.63	42.1
Apr 17	12	21.2	88.3	0.63	-
Apr 17$_{night}$	12	22.2	87.9	0.39	0.0
May 4	10	25.9	78.5	1.17	30.7
May 5	9	27.9	61.0	1.54	48.7
May 9	10	28.1	50.5	2.04	37.2
May 14	6	28.2	61.8	1.01	14.2
May 15	9	30.4	51.3	1.36	42.9
May 21	9	28.8	71.3	1.34	24.4
May 22	9	29.8	62.8	1.24	40.3
May 25	10	29.5	58.6	1.06	39.0
May 26	9	30.4	55.9	1.39	40.3
May 29	10	28.1	70.3	1.03	23.5
May 30	5	27.3	71.6	1.02	31.8
Jun 1	9	30.3	62.5	1.38	36.0
Jun 2	9	29.4	61.7	1.59	41.7

to establish if differences in the internal structure of the product -- possible different diffusion coefficients -- could affect significantly the drying rates of cassava. Llanera variety roots having ages -- time elapsed after planting and before harvesting -- of nine months and two years were chosen for the purpose because of the obvious differences in their internal structure. The old roots were yellowish, soft and spongy while the young ones presented a white, firm structure. In the three day experiment, five identical perforated wire trays -- 50x50x10 cm -- loaded with five kilograms of rectangular bars of cassava were wighed every hour during working hours, Figure 4. Three of the trays were loaded with the two year old roots. Two of these were elevated 30 cm from the floor, and the other was placed on the floor directely. The two trays with the young roots were also elevated 30 cm from the floor. The bottoms of the elevated trays were left free to the air. Desorption curves of experiments are presented in Figure 5. The moisture ratio (expressed in equations 2.3, 2.4, and 2.5) was used as the dependent variable to eliminate the influence of different initial moisture contents. M_{eq} values were estimated to be proportional to those of other starch products because no reported values were available at this stage of the study. The product on the floor changed its original color to brown (Figure 23) and produced fermenting odors indicating that deterioration occurred in the second drying day due to slow

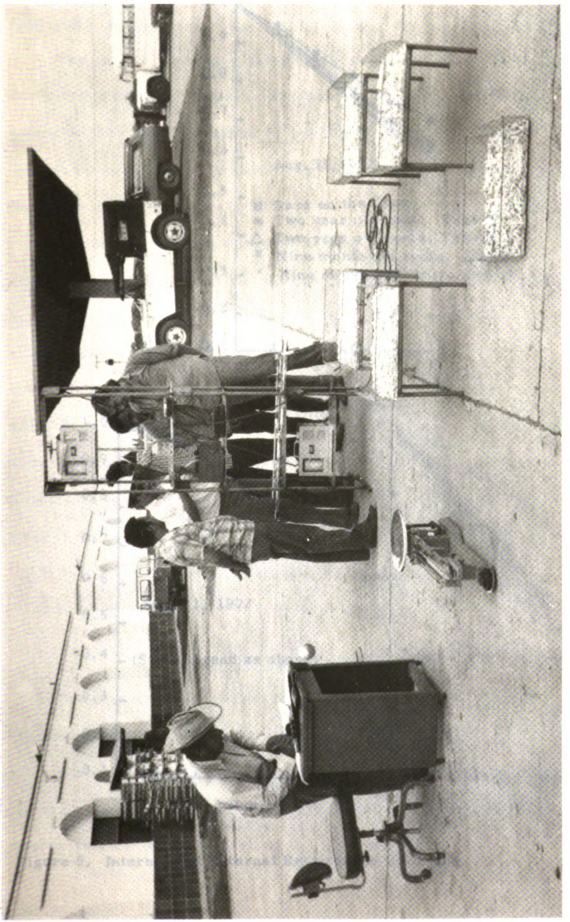


Figure 4. Natural Drying by Horizontal Trays

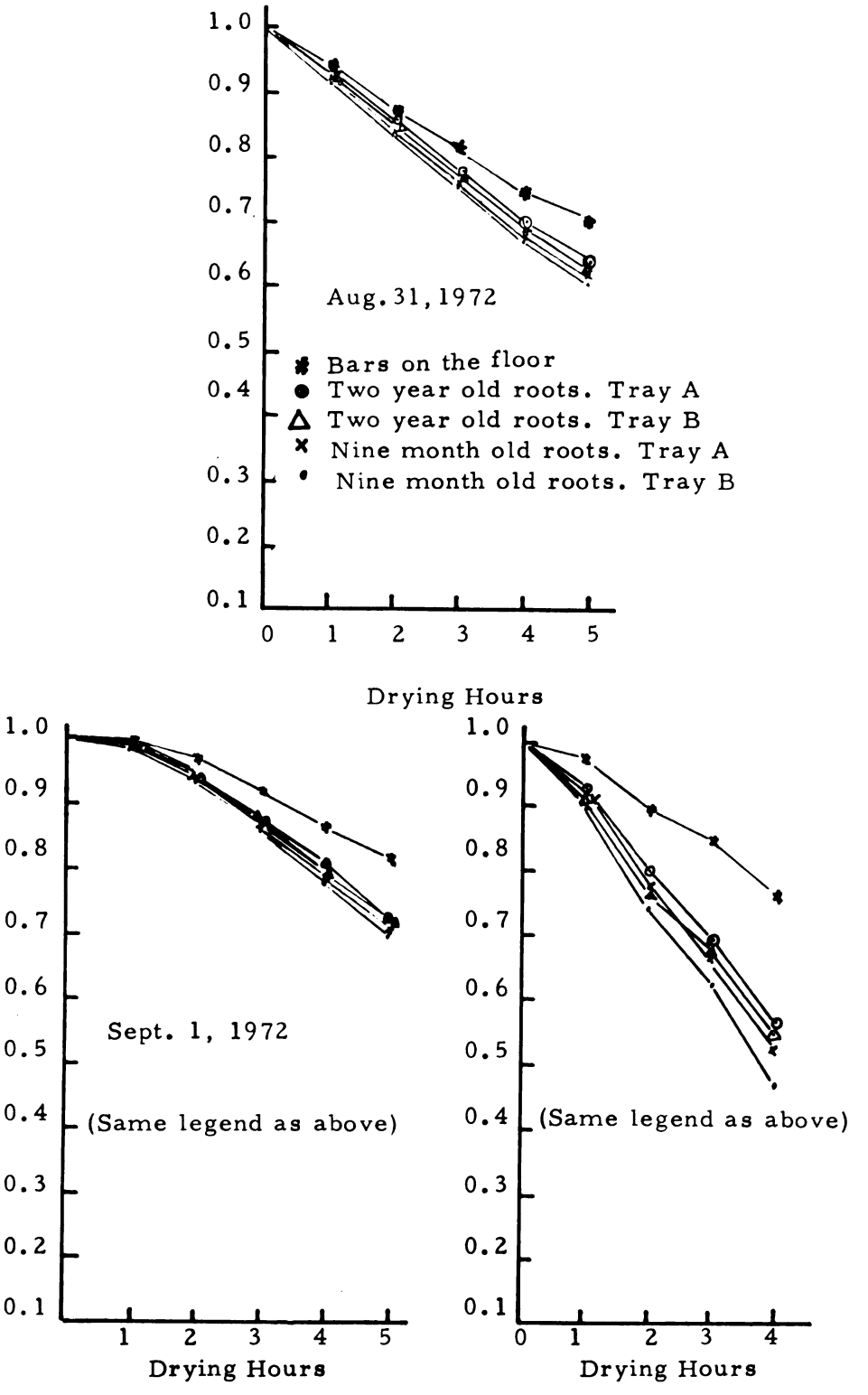


Figure 5. Internal and External Resistances in Drying

deydration rates.

The curves show that although differences in drying can be attributed to different diffusion coefficients, they were small when compared with those originated by modifying the air circulation through the particles. The external resistences to the moisture flow were more important than the internal resistance differences.

No special attention was given in selecting uniform cassava samples for the experiments, although, different cassava structures in age, variety, and position along the roots were recognized. A single experiment showed differences of moisture content higher than 5 percent, wet basis (w. b.), for the same fresh root at different positions along the tuber. A study of dry matter distribution along the roots, reported by Umanah (1971), supports this finding. Unpeeled Llanera variety between 8 to 18 months of age furnished most of the cassava samples used in the experimentation. No significant differences in average drying rates could be attributed to differences in cassava ages and varieties.

4.2 Cutting Mechanisms

The production of the cassava particles received special attention in the study. Two different mechanisms were used to produce sixteen types of cassava geometry, different in their forms of dimensions. The general appearance and schematic views of the mechanisms are shown in Figures 6, 7, 8, 9, and 10.

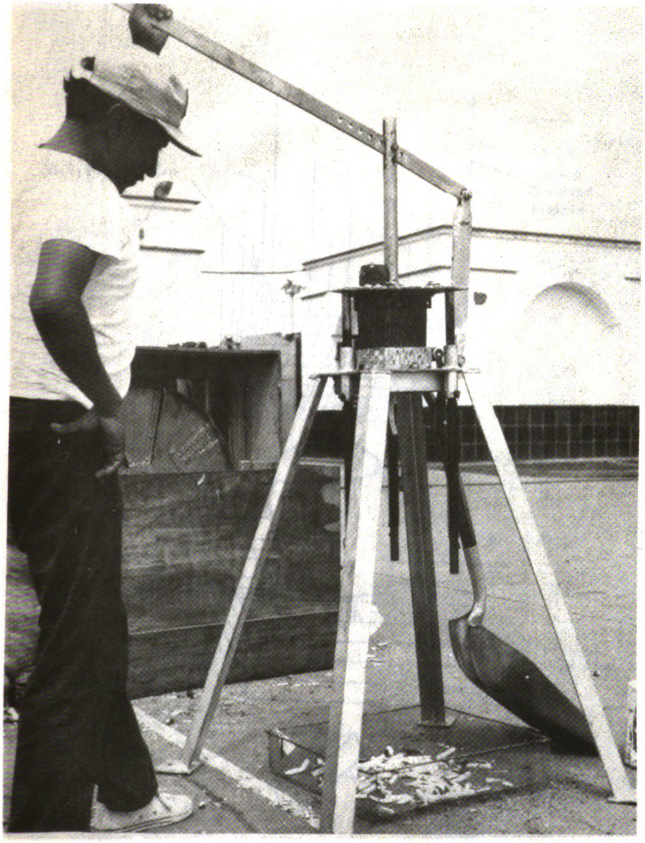


Figure 6. Manual Press to Cut Cassava Rectangular Bars

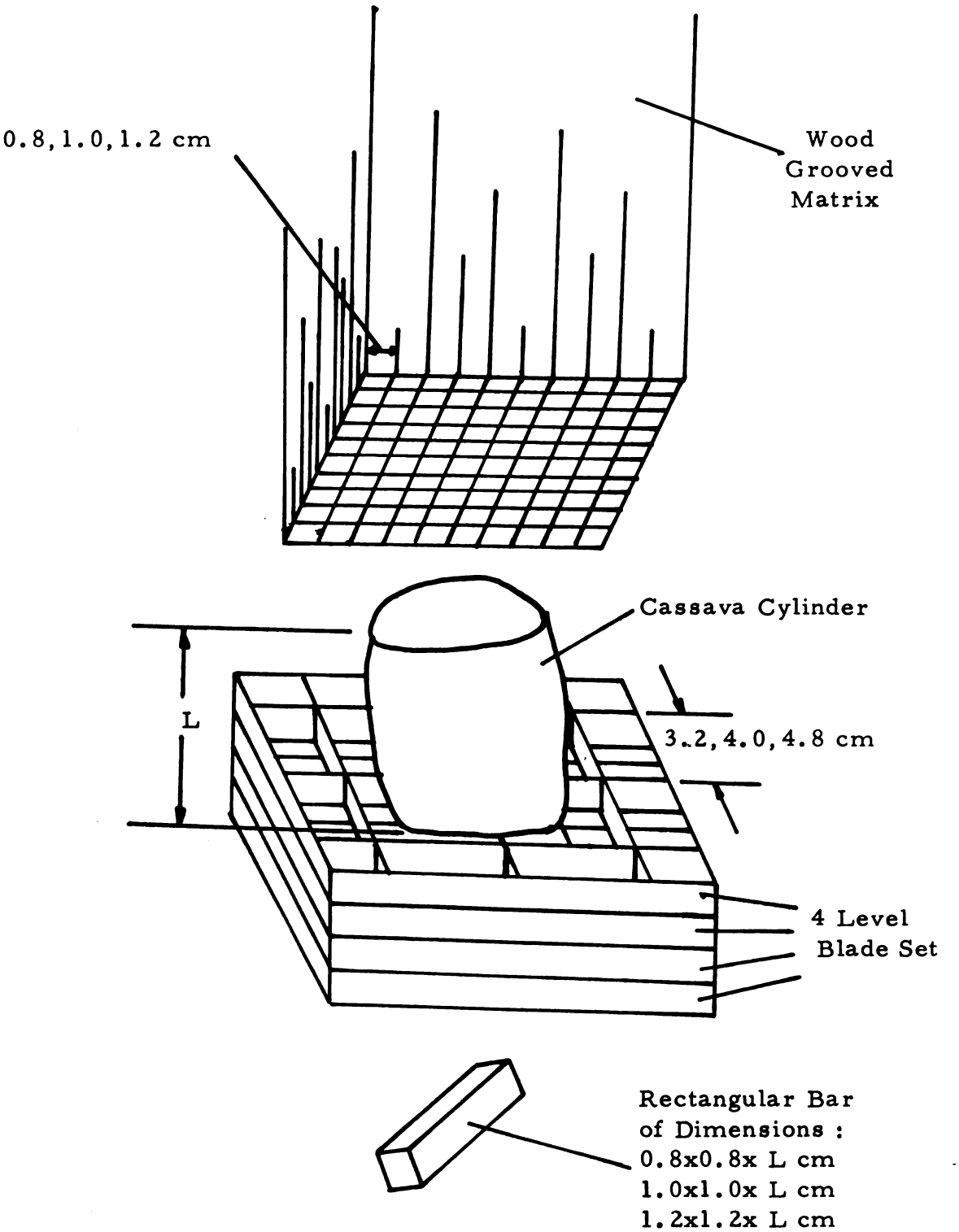


Figure 7. Cutting Section of the Manual Press

Figure 8. Disc Cutter

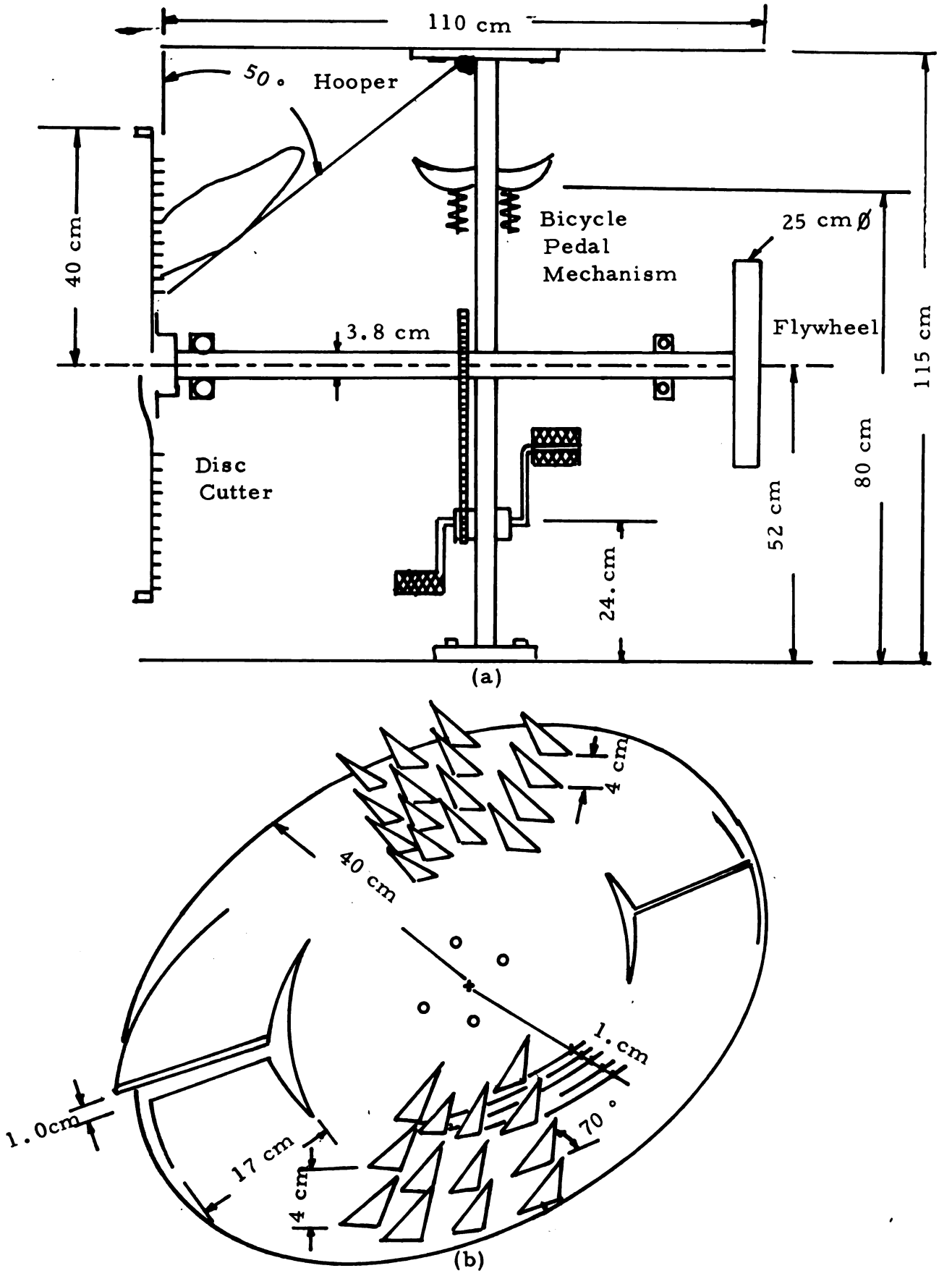


Figure 9. Schematic view of the Disc Cutter Assembly

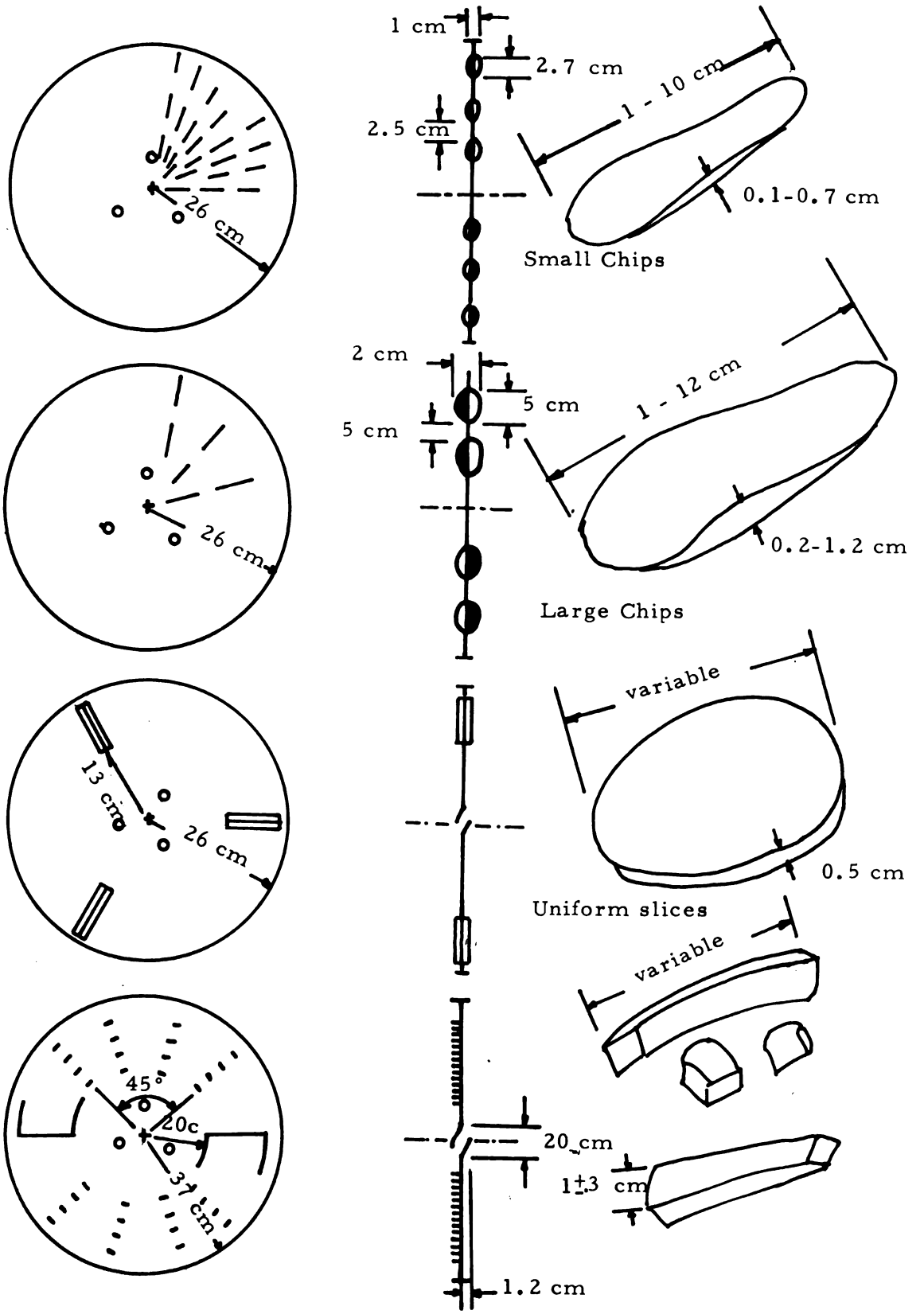


Figure 10. Cutting Discs and Particles Produced.

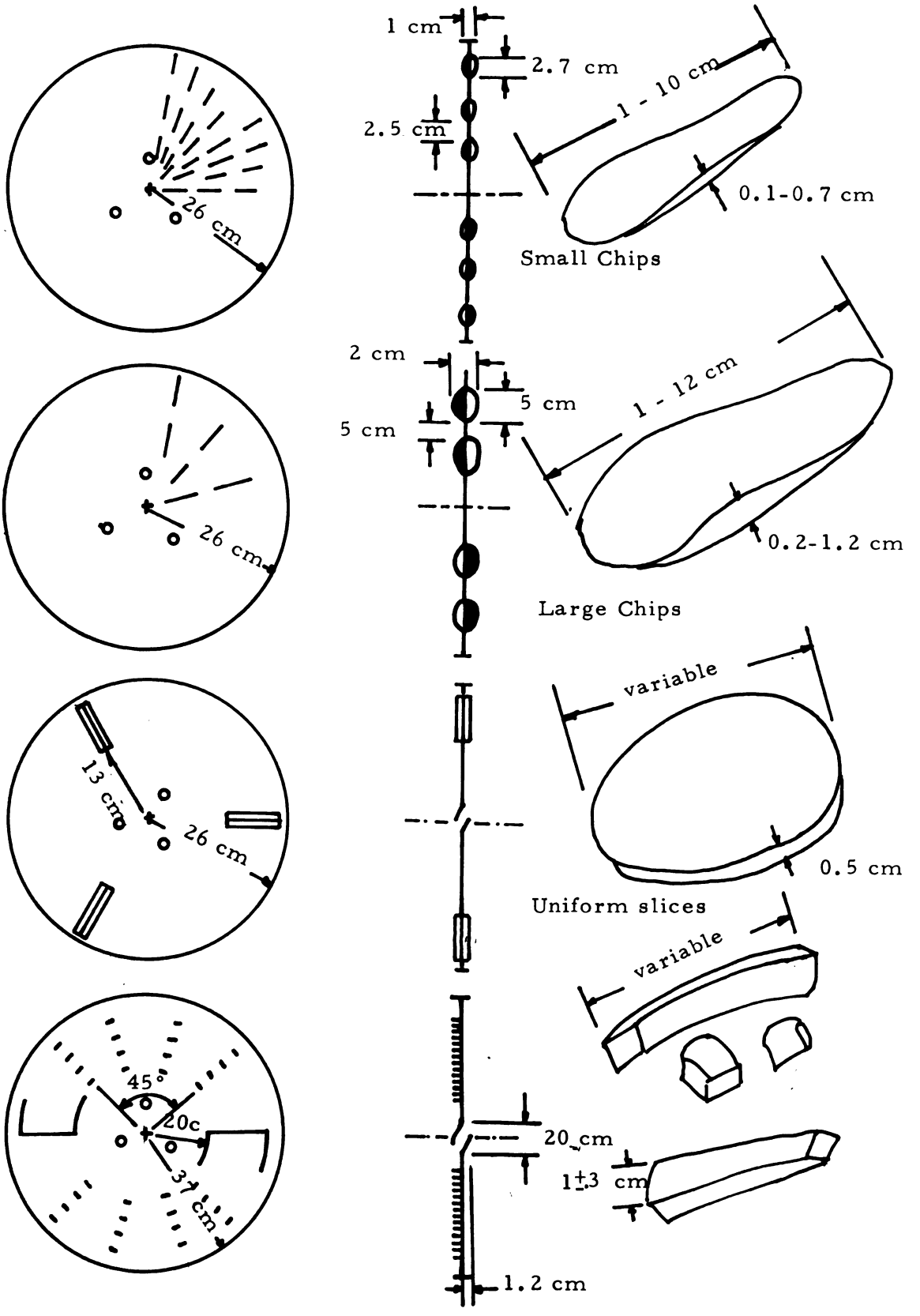


Figure 10. Cutting Discs and Particles Produced.

The first device is a manual press (Figure 6 and 7) consisting of (a) a matrix of rectangular bars made of metal or wood which push a previously cut cassava clyilinder downward, and (b) a stationary set of blades. The cutting set was partitioned in a blade arrangement made in four horizontal planes. Each plane consisting of crossed, vertical, one millimeter steal blades distributed as shown in Figure 7. The four planes were properly aligned to produce thin rectangular bars with dimensions depending on the distances between the blades . Each plane produced a cut to the cylinder. Three sets of knives were made to produce bars with sections of 0.8x0.8, 1.0x1.0, and 1.2x1.2 cm . The bar's length was the height of the cassava cylinder. The product of the press presented a neat solid figure, free of product fines (very small product particles undesirable for drying purposes). One man could cut about 40 kg of cassava per hour.

The second device is a model of a chipper used in the southeast Asian cassava exporting countries. It consists essentially of a circular disc with built-in knives which cut the root when fed in the hopper (Figure 8). The disc can be powered by a person using a bicycle pedal mechanism, by the power take-off of a tractor or by a motor. The conventional disc and three modifications were used to obtain different geometries. A schematic view of the discs and the approximate form of the chips are shown in Figure 10.

A more detailed illustration of the disc which produces a geometry resembling the rectangular bars (1.0x1.0x3.0-9.0 cm) is given in the bottom of Figure 9. In this particular disc a small series of knives about one and half millimeters thick were soldered along concentric radii to the disc. The root is cut first by these knives producing grooves one centimeter apart. A second set of large blades make the final cut to produce the rectangular bars of variable length.

The end products of the disc cutter presented a weak internal structure due to shearing stresses produced in the cutting of the particles and the release of them by the disc. Product fines were also produced but they could be reduced when the roots were positioned firmly. In this case a second man was required to feed the roots.

Yields of this mechanism were about 240 kg/hr when operated by a man or about 500 kg/hr when operated by an engine.

4.3 Field Experiments. First Experimental Period

The field experimentation was divided in two periods: (a) from August 31 to October 27, 1972 and (b) from March 7 to June 2, 1973.

During the first part, experiments were designed to compare the reported drying methods with possibly more efficient ones and to obtain data that could be analyzed to identify the relative importance

of each environmental variable on the drying process. In the second period, similar experiments were performed but quantitative knowledge of the process permitted experiment with improved models to the point that a close prototype of the recommended drier for a commercial operation was built and tested.

The experimentation of the first part consisted basically of the following general procedures: (a) a given amount of a cassava geometry was placed on horizontal perforated trays, separated one from the other by a distance at least equal to the tray length, or in two types of solar dryer (Figures 4 and 12), (b) the loaded tray or cabinet was weighed at one hour intervals during the working hours of one, two, or three consecutive days. Figure 11 shows the desorption curve for a two-day natural drying experiment, (c) measurements of the variables were taken during the experiments at one hour intervals, (d) at the end of the experiments the product was placed in convection type ovens at 75°C for 48 hrs to estimate the dry matter content. A detailed description of the tests follows.

4.3.1 Horizontal Trays

All trays used were made of galvanized iron mesh (0.5 mm spacing between wires). Tray dimensions were 50x50x10 cm. Heavier galvanized iron wire reinforced the tray structure. The trays rested on supports made of conduit tubes, designed to not interfer witn the air circulation underneath the trays (Figure 4).

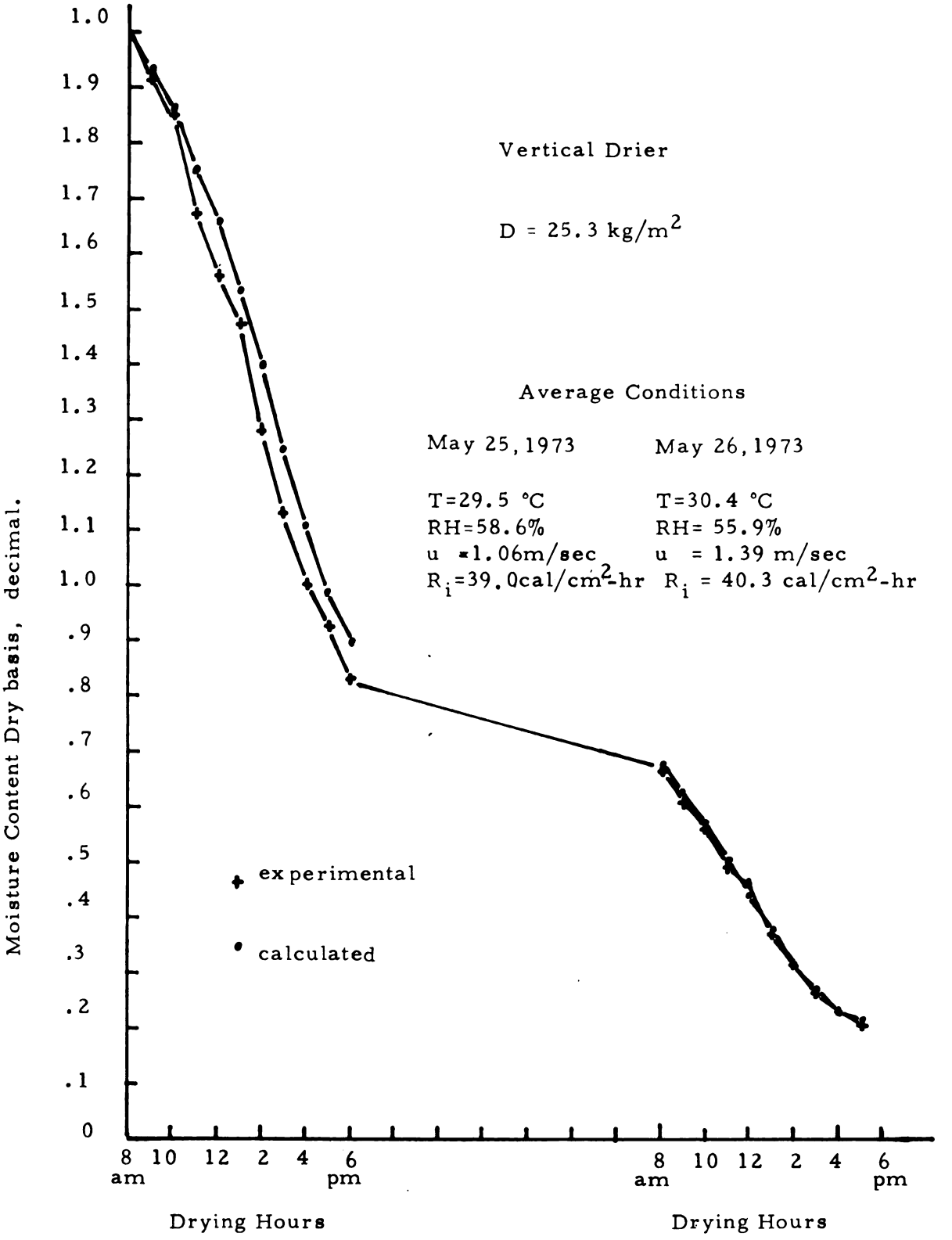


Figure 11. Drying Performance in two Consecutive Days.

4.3.2 Solar Driers

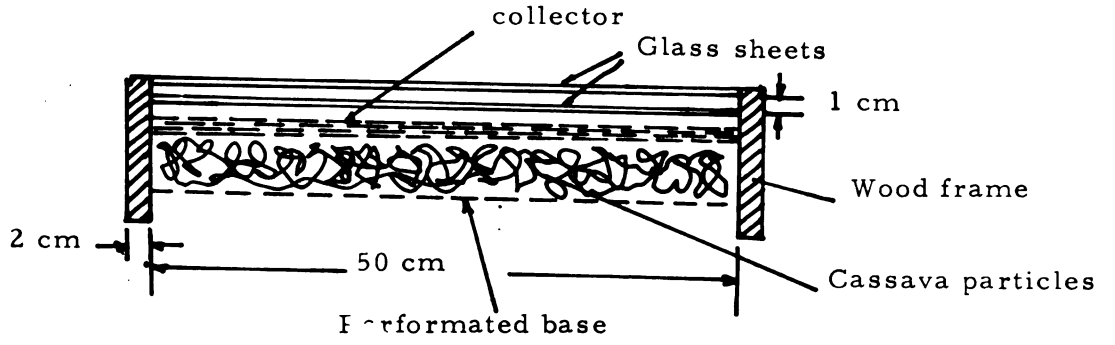
Two types of solar dryer were tested. The first consisted of a collector, made of a series of wire screens painted with a lamp-black base enamel and covered by two sheets of window glass (Figure 12a). A vertical wood frame made of plywood prevented lateral heat losses and gave support to the collector and glass sheets. The product was positioned inside the frame using three configurations: (a) on a wire tray at about 10 cm from the collector, (b) on a perforated plexiglass sheet touching the collector and the screen resting on the top of a baffle system of corolite crossed rectangular plates 2 cm apart and 8 cm high. This type of solar dryer is denominated as a solar cabinet.

The second solar drier tested consisted of the same glass sheet arrangement with a collector made of a black metal sheet with a fin system soldered on its back (Figure 12b). The chips were placed in a perforated tray and the collector fins rested on the particles.

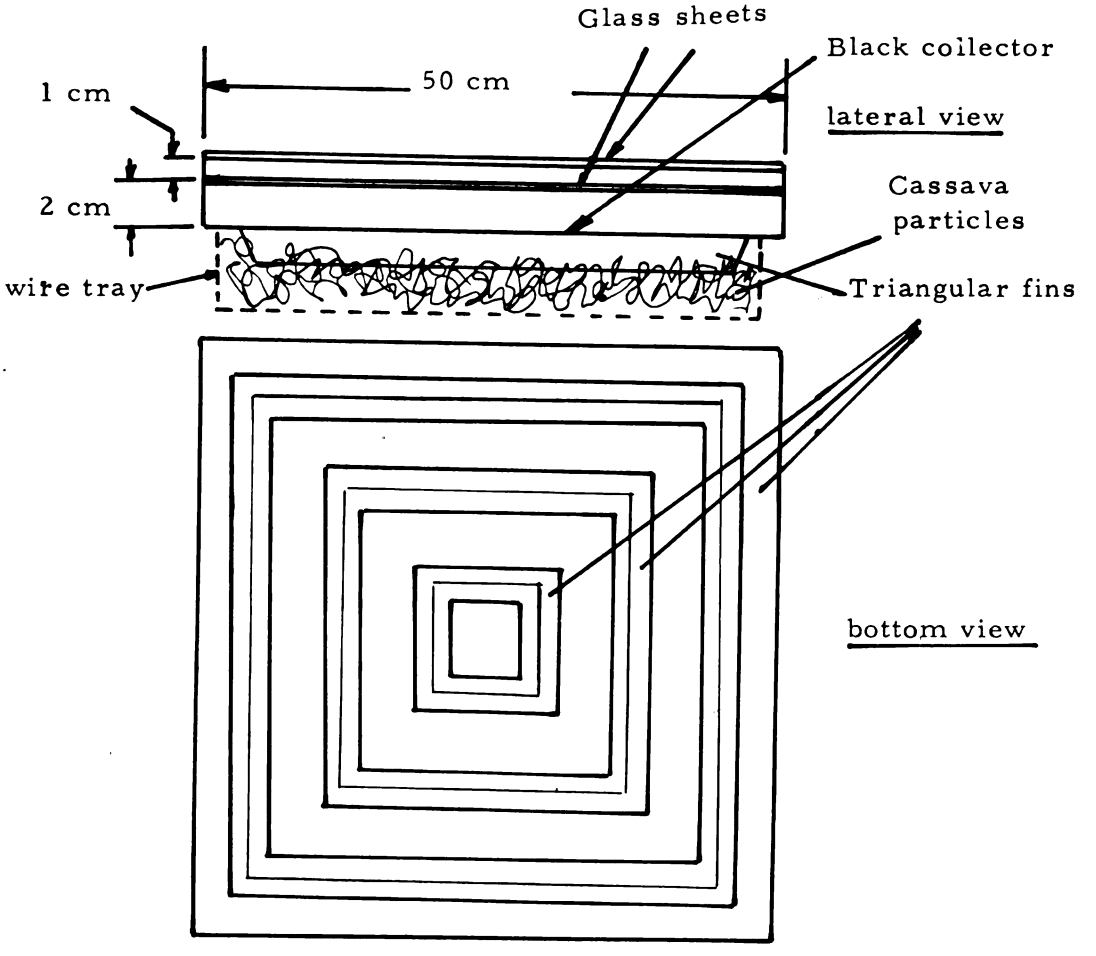
4.3.3 Measurements and Instrumentation

Wind velocity was measured hourly by reading the counter of a totalizing Belfort 3 cup anemometer, Cat. No. 5-349-A. The cup centers were positioned 30 cm above the floor.

Dry bulb temperature and air relative humidity were averaged for each hour from the recording chart of a Belfort hygrothermograh,



Solar Cabinet
(a)



Solar Collector
(b)

Figure 12. Solar Driers

Cat. No 5-594, placed at 30 cm above the floor. A weekly gear and chart set was used during the first experimental period and a daily set for the second. Temperature average was meassured approximately within ± 1 °C error with respect to a potentiometer. The air relative humidity was measured within ± 2 percent error with respect to a aspirator pshychrometer.

Total incoming shortwave radiation was measured by a Grczynsky solarimeter (Solorgor) during the first period and part of the second part. The signal was integrated hourly and printed by an EKO solar printer (Solarin), model RR-11.

The trays were weighed each hour in a Ohaus beam balance, 20kg of capacity and 1 g of sensitivity. Errors in weighing measurements were less than 1 percent of the total weight.

A portable Honeywell potentiometer with copper-constantan 24 gauge thermocouples and an Athkings portable aspirator pshychrometer were used to make auxiliary measurements of the drying product and to calibrate other instruments.

Indications of the percentage of short wave reflected radiation from the horizontal cassava trays were determined with a portable EKO Line pyrheliometer connected to a millivoltmeter.

The experimental data of the first experimental period was utilized to graph, in preliminary analysis, the natural desorption curves.

4.3.4 Preliminary Results and Analysis

Observations of desorption curves during the first experimental period helped to identify some obviously inferior forms of natural drying of cassava and to gain knowledge on the physics of the process.

Figure 5 shows that by elevating the perforated trays from the floor, the drying efficiency improves significantly (the quality of the end-products can be appreciated in Figure 23).

Figure 13 shows the solar cabinet perfomances compared with natural drying of the same product on perforated, elevated trays. The solar cabinet and the solar collector tested did not result in appreciable advantages over natural drying although high radiation levels were recorded during the tests. (See Table 3 and Appendix B).

Figure 13c shows the dehydration curves of untreated cassava bars and the same product dusted with black activated charcoal powder. The differences can be attributed to the higher solar absorption of the black surfaces.

Two sizes of the conventional cassava chips (Figure 14) are compared with rectangular bars, 1x1x5 cm, for three initial layer loads or densities [1] : 8, 12 and 16 kg/m^2. Curves (a) and (b) show that no

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[1] Densities are defined in this study as the initial fresh weight per unit area (kg/m^2) . The density values (D) are proportional to the product dry weight used in the analysis.

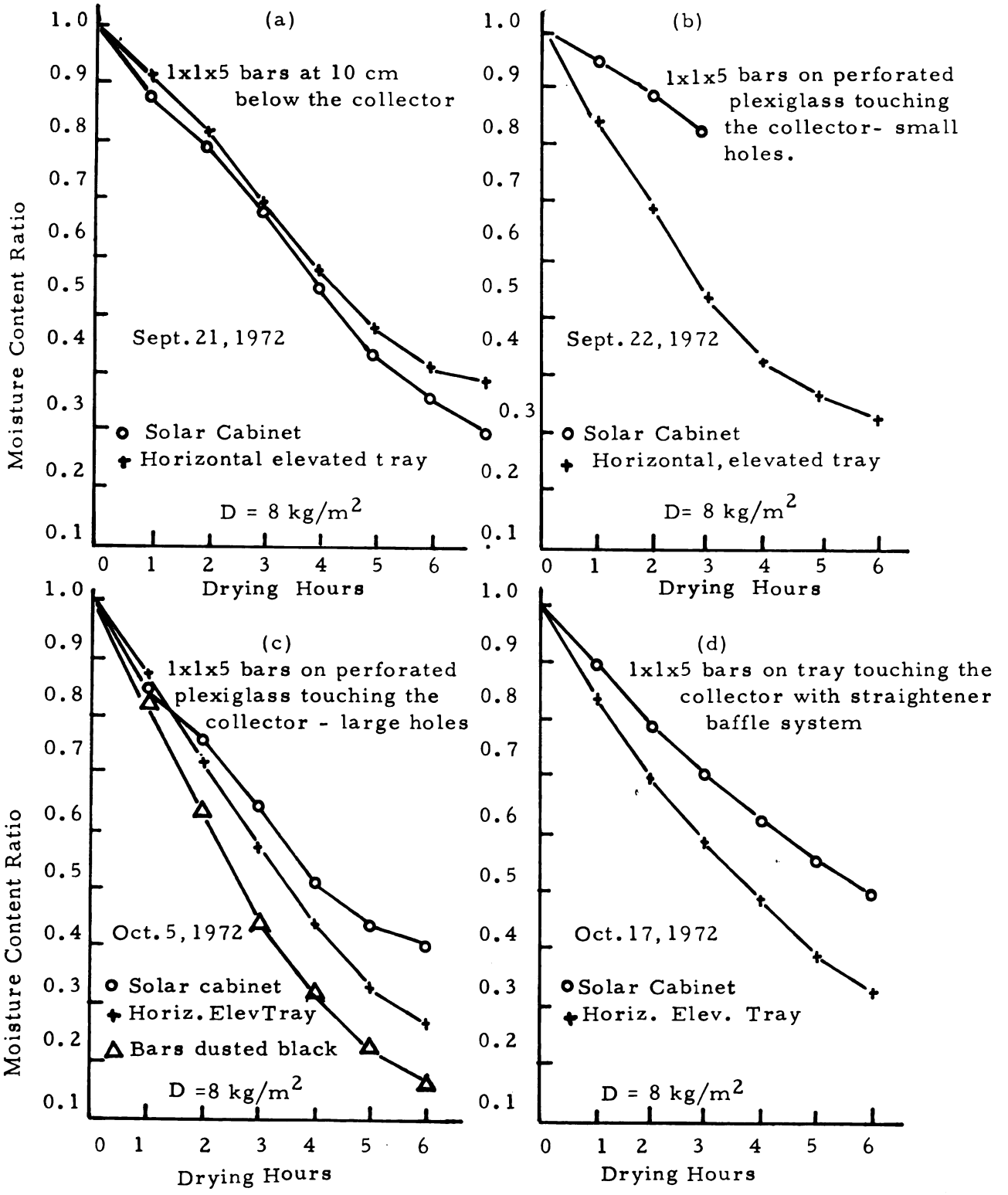


Figure 13. Solar Cabinet Performances

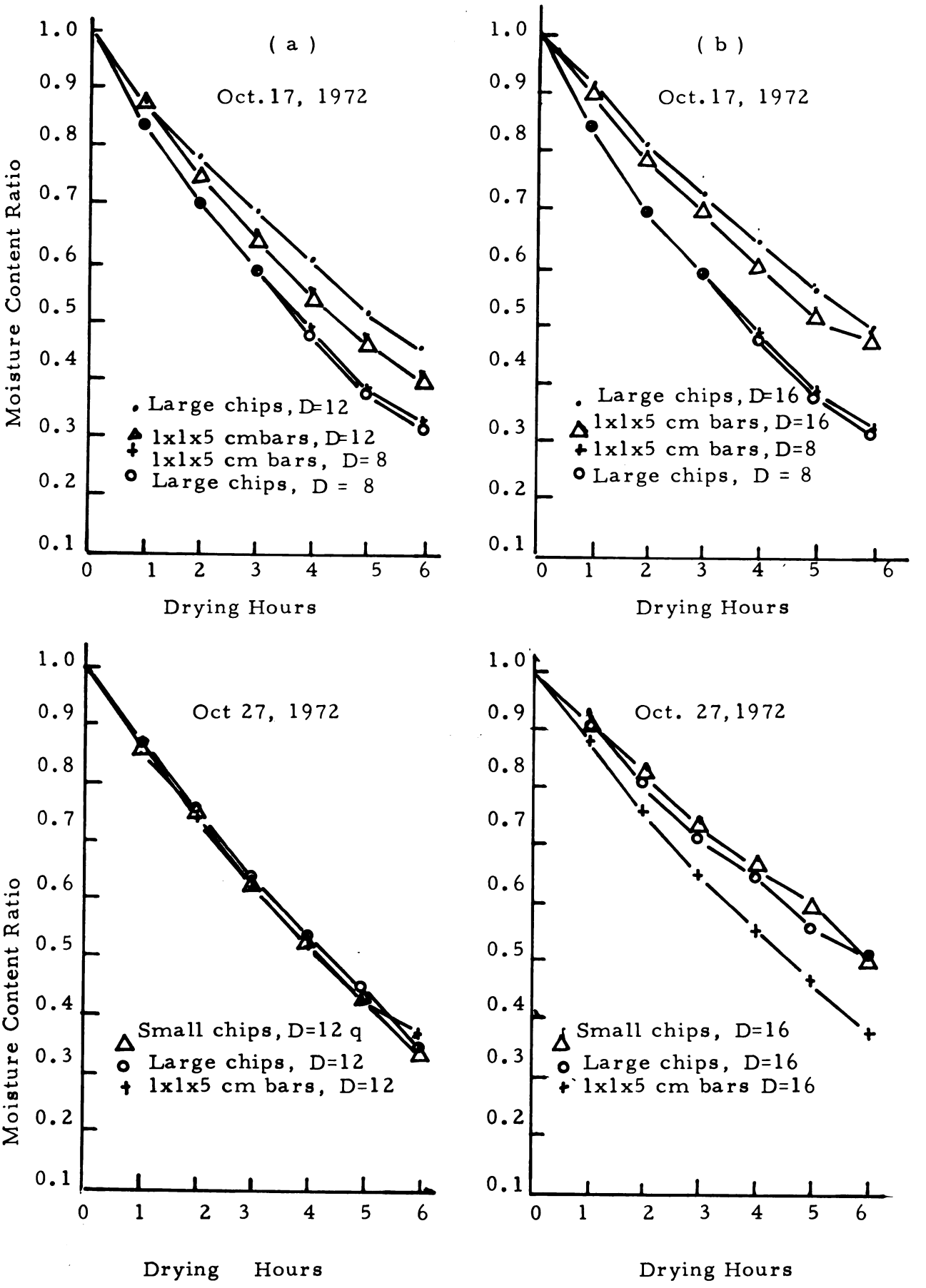


Figure 14. Performances of Different Cassava Geometries.

differences could be observed for the thin layer but large differences, due to a better air circulation promoted by the rectangular bar geometry, were found for the thicker layers. The drying characteristics of the big chips were superior to those of the small ones for 16 kg/m^2 because of higher void space (porosity) between the particles (Curves c and d).

The hourly stirring effect on densities of 16 kg/m^2 was only of 0.03 (moisture ratio) after six hours of sunshine. This experiment (not shown in the graphs) also indicates the low solar absorption of the white cassava surface.

Although the study of the dehydration curves gave an insight into the problem, it was not possible to establish the particular effects of the ambient variables. The unlimited combinations that could be drawn in the design of the experiments together with the limited number of experiments per day (to minimize errors due to different weighing times, the number of trays was limited to nine) indicated that an understanding of the phenomenon was mandatory in order to suggest better drying forms.

The first attempt made was to calculate a drying parameter which is nearly independent of the current moisture content at any instant of the drying process. The proportionality drying constant K of the empirical layer equation (2.6) was estimated by the finite-difference expresion valid for any time:

$$\overline{K'} = \left[\frac{M_{i+1} - M_i}{\Delta t}\right]\left[\frac{1}{\frac{M_{i+1} + M_i}{2} - M_{eq}}\right] \qquad (4.1)$$

where M_{i+1} and M_i represent two consecutive values of the average moisture content with Δt equal to one hour. The assumed values for M_{eq} (see section 4.1) were taken for cassava as function of the average wheather conditions.

The choice of equation (2.6) for the preliminary analysis was supported by the results of drying a thin layer of cassava slices under controlled conditions in the agricultural Engineering Processing Laboratory at Michigan State University, and (b) by the drying data of Chirife's studies (1970 and 1971). Booth sets of results are reproduced in Figure 15.

The experimental $\overline{K'}$ and the ambient conditions were drawn for each day. Figure 16 and 17 show some examples.

An ordinary linear least squares standard IBM (1130 System) routine was used to investigate the relative importance of the environmental variables in the natural drying phenomenon. The model proposed was [1]:

$$\overline{K'} = a_0 + a_1 \overline{u} + a_2 \overline{R}_i + a_3 \overline{T} + a_4 \overline{H} \qquad (4.2)$$

1 This method is an approximate approach to the general procedures of estimation of parameters (Beck, 1972) in a differential aquation. See discussion in Chapter V.

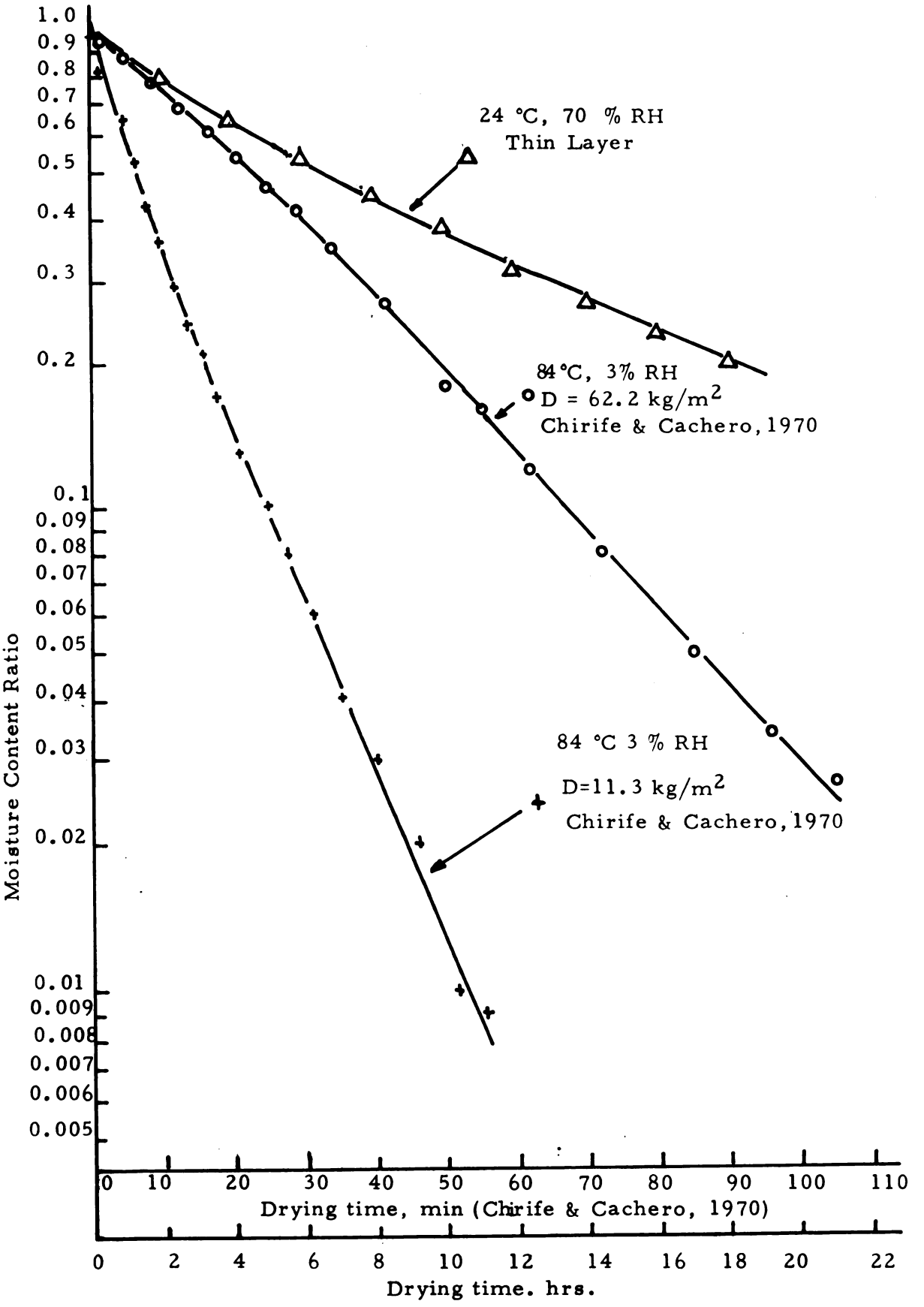


Figure 15. Desorption Curves at Fixed air Conditions

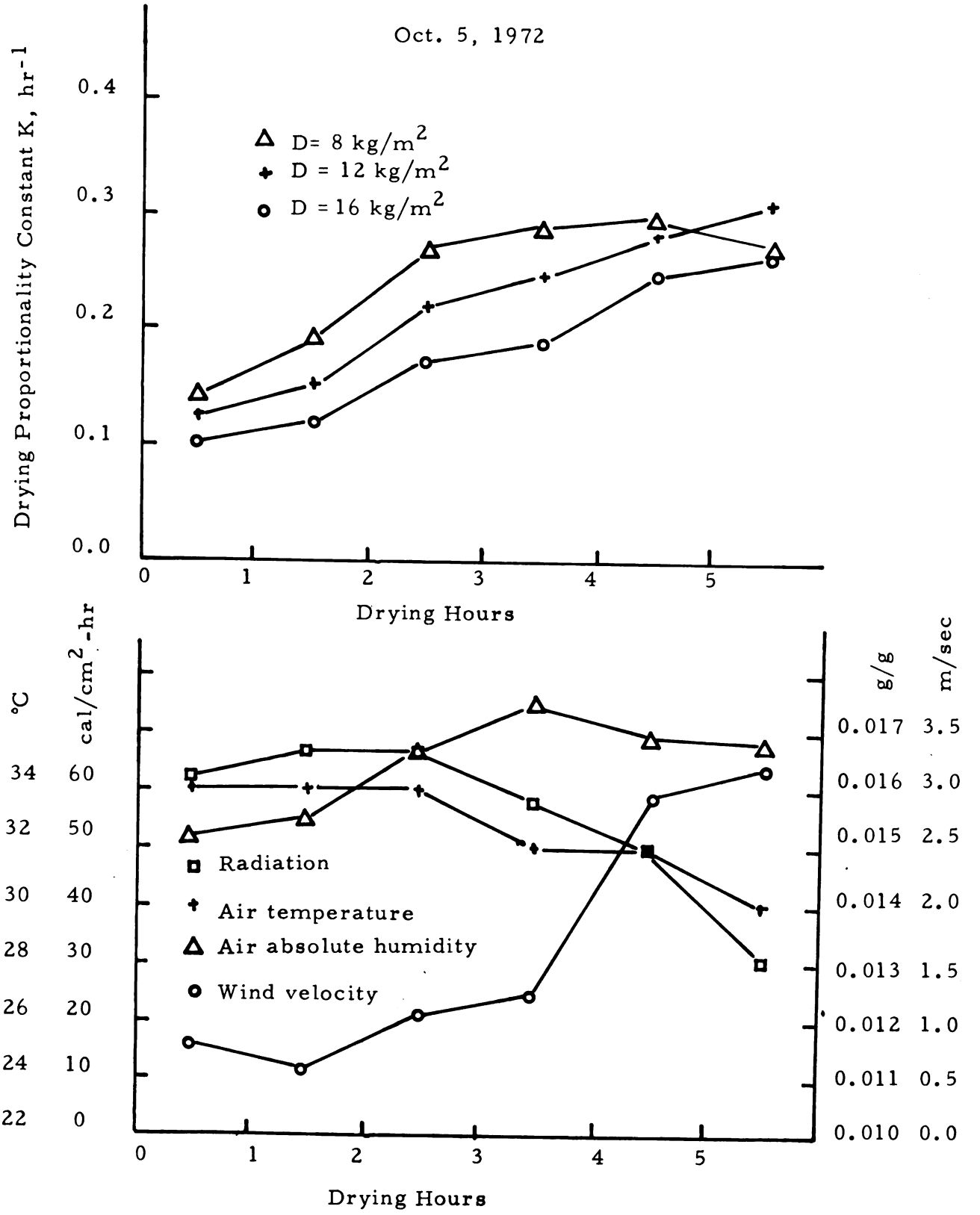


Figure 16. Influence of Ambient Conditions on Drying.

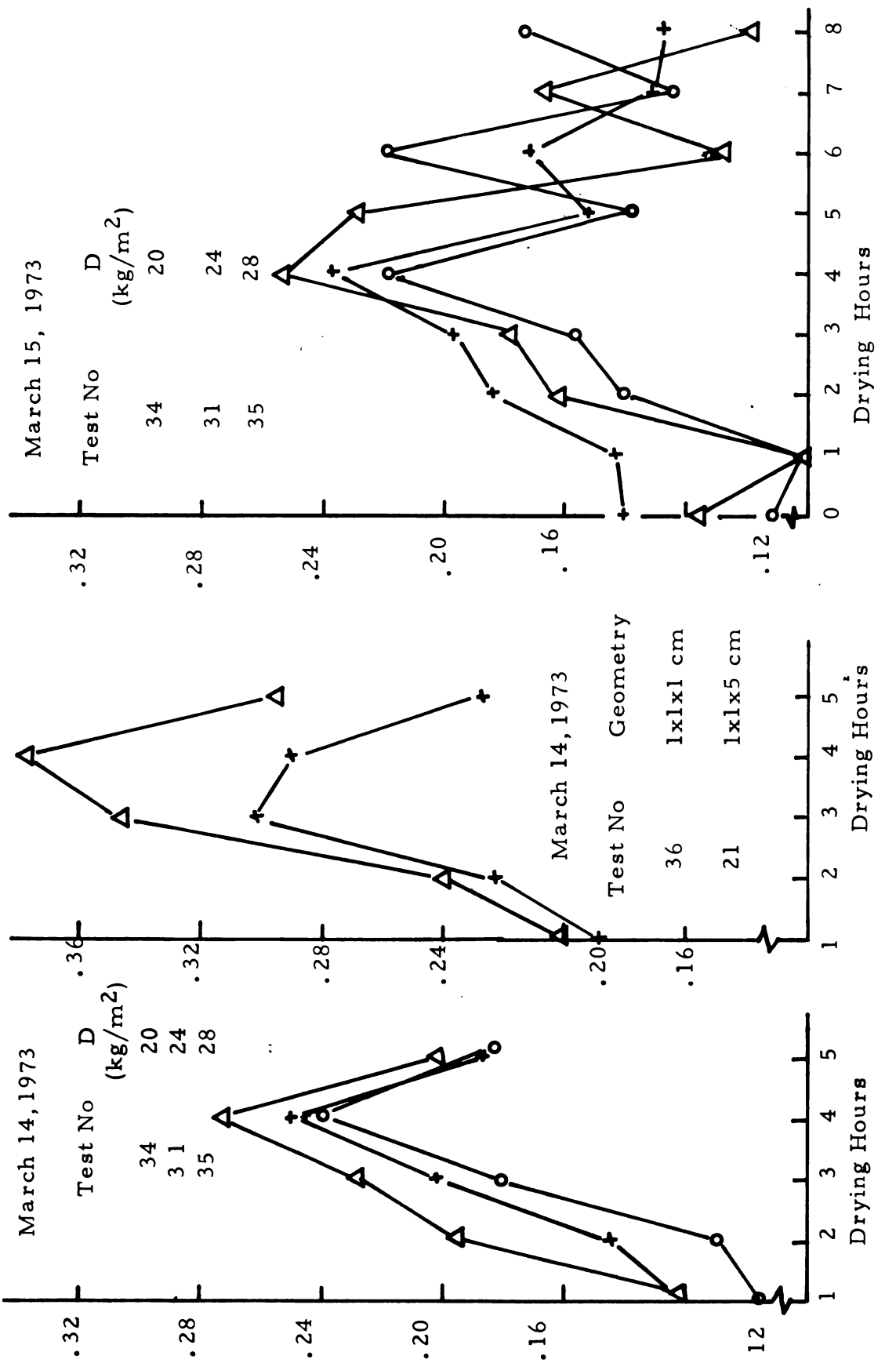


Figure 17. Characteristics of the $\bar{K}$ values

where $\bar{u}$, $\bar{R}_i$, $\bar{T}$, and $\bar{H}$ are the average wind velocity, incident radiation, air dry bulb temperature, and air absolute humidity for each elapsed hour. The $\bar{K}'$ values correspond to experimental tests of the same product geometry and density.

Statistical tests associated with the linear regression indicated that dry bulb air temperature and wind velocity variations explained about 75 percent of the changes in the $\bar{K}'$ values. The regression coefficients a_2 and a_4 were not significantly different from zero. (The results of the regression analysis are not shown for this preliminary test).

The regression results suggested possibilities of improving the already satisfactory performances of the elevated horizontal wire trays.

4.4 Field Experiments. Second Experimental Period

4.4.1 Black Floor

A 10x10 m^2 area covered by a layer medium gravel was painted with a lamp-black base enamel. Temperature differences of 1, 2, and 3 °C could be measured at 10 cm above the floor with respect to the natural adjacent soil. The temperature differences depended on the evironmental variables, the higher differences corresponded to the case of high radiation and low wind velocity. No attempts were made to study this complex micro-meterological phenomenon that supports the finding of Aderinkhin (1951).

4.4.2 Vertical Trays

The 50x50x10 cm trays were adapted with a mesh frame to permit sandwiching of the cassava layer and to place them in a vertical position with the aid of a screw mechanism and an iron structure (Figure 18). The vertical layers were positioned against the predominant direction of the winds. This position was the most unfavorable with respect to the recepted solar radiation.

Weighing and weather variable measurements were made in the same form outlined in the first experimentation period. Ovens set at 100 °C were used for dry matter determination.

4.4.3 Vertical Driers

An experimental drier was built and tested during the last part of the study (Figure 19). The unit consisted essentially of two 1.5x2.0 m vertical and parallel frames covered with galvanized wire screens (8 mm spacing between the 1 mm wires).

The frames were pinned on two vertical wooden boards set in the ground. The boards also served as the lateral walls of the drier. A roof was supported by the boards. Provisions were made (a) to vary the distance between the screens, (b) to load the drier by a hopper built on the top, (c) to unload the drier by a door hinged at the botton of one of the frames and (d) to unpin the drier and let it rest on a platform scale for continuos weighing. When the drier rested on the scale it also touched one of the horizontal iron angles that joined the boards on

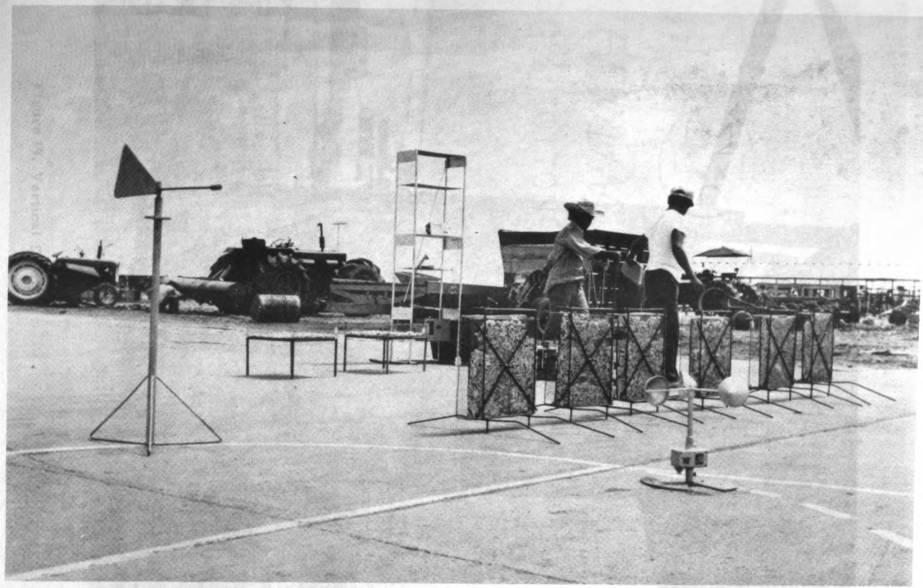


Figure 18. Natural Drying by Horizontal and Vertical Trays

Figure 19. Vertical Drier

Figure 20. Vertical Drier Modified with Wings

the top. Friction forces due to this interation and those between the product and the lateral drier walls were tested to be about 0.5 kg while the average load of drier was above 50 kg. Sensitivity of the scale was about 0.5 kg.

Better drying effects were designed for by adding four wings to the drier as shown in Figure 20. The experiments with the modified drier constituted the end of the field experimentation.

4.5 Summary of Total Number of Observations

The complete distribution of the hourly measurements during the study is summarized in Table 4. More that 70 percent of the observations came from tests with bars of section 1 x 1 and 1.2 x 1.2 cm^2, on vertical and horizontal trays. Discrimination of these with respect to layer densities and lengths of the bars are presented in Table 5.

Fifty-four percent of the possible evaporable water (average value) was dried during the daily experiments. In some experiments, however, only 13 percent of the potential evaporable water was lost, while in others 75 percent was removed. The mean hourly moisture content for all measurements was 48.6 percent, w.b., but the entire practical moisture content range for cassava (67 to 12 percent, w.b.) was recorded in the experiments. The tests lasted one, two or three consecutive days. Daily measurements were taken during a period of 3 to 12 hours with an average value of 7 hours. The detailed data is presented in the Appendix B, a summary of the average weather variables for each experimental day

Table 4. Total Number of Hourly Observations

Drying System	Rectangular Bar Sections			Geometries Small Chips	Large Chips	Disc Bars	Slices	Total
	.8x.8	1.x1.	1.2x1.2					
Vert. Trays	7	490	172	-	-	261	-	930
Hor. Trays	14	429	102	12	24	89	8	678
On Floor	-	31	-	-	-	-	-	31
Solar D.	-	23	-	-	-	-	-	23
Vert. D.	-	-	-	-	-	54	-	54
"& Wings	-	-	-	-	-	70	-	70
TOTAL	21	973	274	12	24	474	8	1786

Table 5. Distribution of Observations for the Rectangular Bars.

VERTICAL TRAYS

Density (kg/m^3)	Section: 1x1 cm^2 Length (cm)								Section: 1.2x1.2 Length		
	½	2	3	5	7	8	9	Total	5	7	Total
16	-	-	-	44	14	-	-	58	38	14	52
20	47	11	29	101	15	-	7	210	74	-	74
24	23	11	12	67	-	30	-	143	35	-	35
28	12	-	12	40	-	15	-	79	11	-	11
TOTAL	82	22	53	252	29	45	7	490	158	14	172

HORIZONTAL TRAYS

8				54	-	-	-	54	-	-	-
12	-	-	-	24	-	-	-	24	-	-	-
16	25	11	-	40	-	14	-	90	14	14	28
20	7	-	-	219	-	-	7	233	74	-	74
24	-	-	-	27	-	-	-	27	-	-	-
TOTAL	32	11	-	364	-	14	7	428	88	14	102

are presented in Table 3.

The temperature varied from 20 to 35°C, relative humidity from 40 to 95 percent, wind velocity from 0 to 4.6 m/sec, and solar radiation from 0 to 75.9 cal/cm^2 - hr.

4.6 Laboratory Experiments

Selective properties of cassava were evaluated in the laboratory to explain their importance in natural drying of cassava. The significant properties are : porosity, bulk density, and equilibrium moisture content.

4.6.1 Porosity

Porosity P, or void space fraction of the total volume of the cassava particles was measured by a wet procedure. A cylindrical tank, 31.5 cm in diameter and 38.3 cm in height was filled by releasing gently and randomly the fresh product particles. Water was added to complete the tank volume. The volume fraction of water represented the void space fraction of the complete volume of the tank. This simple procedure was readily applicable to cassava because its saturated initial state and because of its higher density than water. Porosity values for different rectangular bar dimensions are presented in Figure 21. Porosity values of the bars produced by the disc were

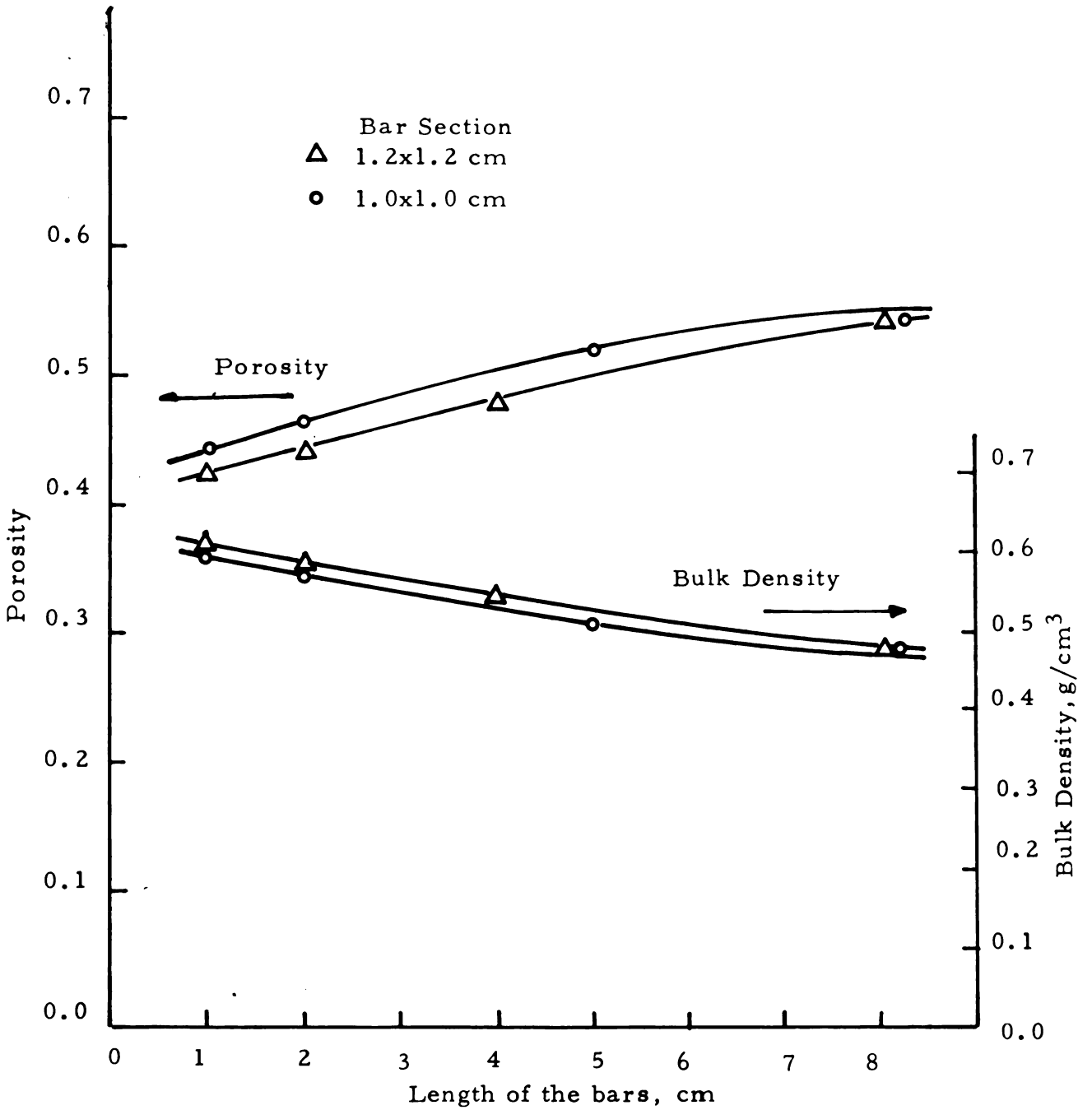


Figure 21. Porosity and Bulk Density of Rectangular Bars.

about 0.5. Conventional cassava chips presented values between 0.42 to 0.46.

Porosities of the particles made by the disc had the tendency to reduce the compression forces due the weight of the particles. The weak structure of the disc products caused this phenomenon. Cassava bars produced by the manual press maintained their original firm structure. Porosity of the rectangular bars were fitted to equation (5.16).

4.6.2 Bulk Density

Bulk density of fresh cassava bars (1x1x5 cm) was measured by weighing the tank, used in the porosity determination, filled with the particles. The value was 0.51 g/cm^3. This figure and the 0.52 porosity value corresponding to this geometrical figure (Figure 21), gives a true cassava density value of 1.06 gm/cm^3. Bulk density of cassava d_b can be expressed in g/cm^3 by

$$d_b = 1.06 (1 - P) \qquad (4.3)$$

Bulk density figures are also presented in Figure 21.

4.6.3 Layer Thickness

The initial layer thickness (L_t) can be given by

$$L_t = 10 \frac{D}{d_b} \qquad (4.4)$$

where D is the density in kg/m^2, d_b the bulk density in g/cm^3 and L_t the layer thickness in cm. An approximate estimate of the initial layer thickness in cm can be obtained by dividing the initial layer density in kg/m^2 by 5.

4.6.4 Equilibrium Moisture Content

Saturated salt solutions were used for conditioning dried cassava bars. Fresh cassava was not used in the experimentation, i.e., no hysteresis effects were studied. One hundred and twenty ml, wide mouthed jars were equipped with stainless steel wire screens supported by tripods with the same material inside the jars. Two of three cassava bars were placed on the screen above the solution level. The jars were kept at fixed temperatures in a growth chamber or in a forced convection oven. Temperature accuracy was within $\pm$ 2 °C. The samples were left until they reached constant weight. Conditioning times varied from seven to ten days. The solutions, temperatures and relative humidities of the conditioning air are presented in Table 6.

Equilibrium moisture content was determined by drying the conditioned bars in forced convection ovens at 100°C for 48 hours. A precision Mettler balance, sensitive to the milligram, was used for the measurements. The data points and adjusted equilibrium isotherms are presented in Figure 22. Description of the adjustment procedures is given in the next chapter. The observed errors can be attributed to the possibility of non-homogeneous cassava samples, mold growing in the

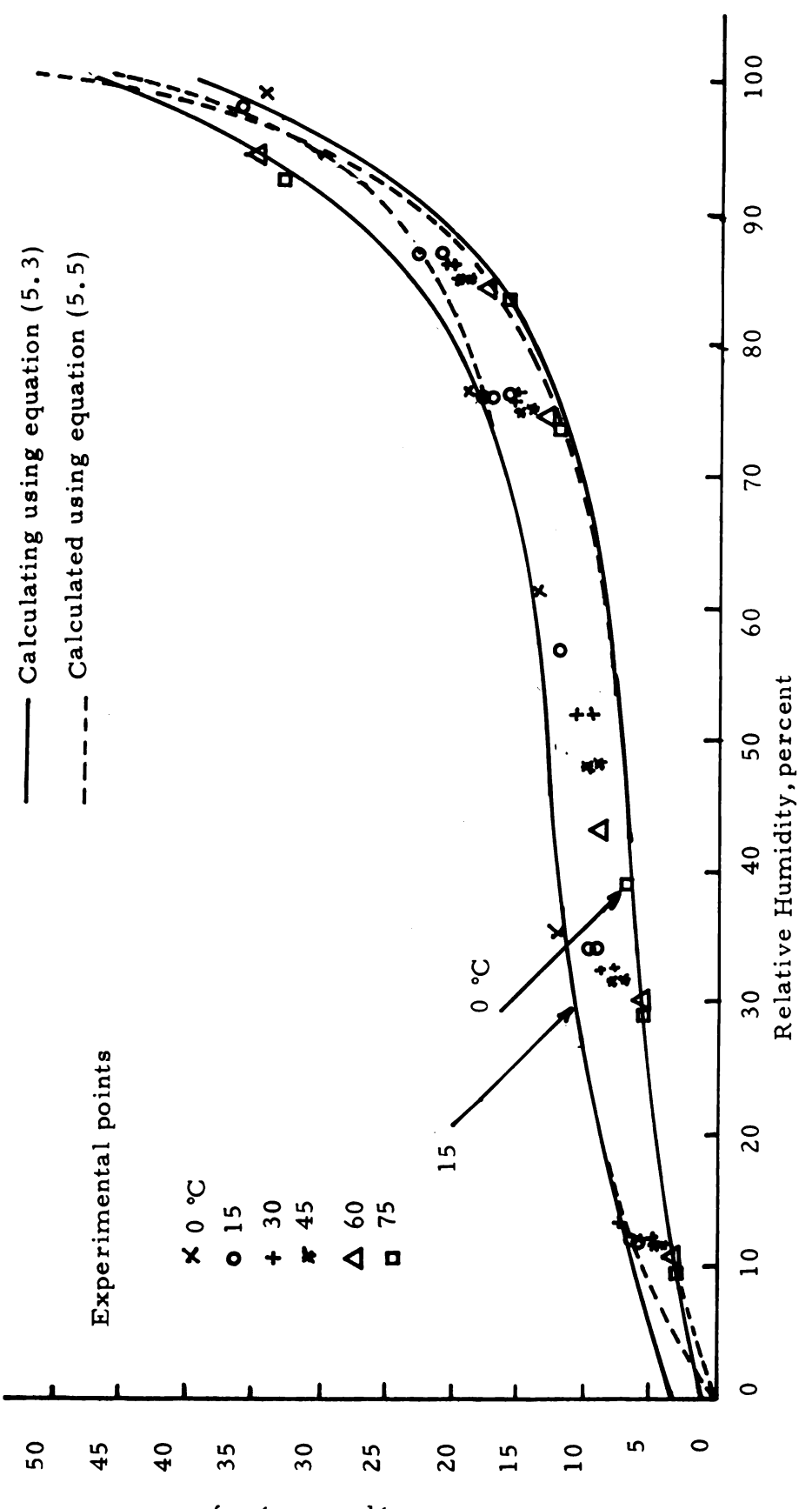


Figure 22. Equilibrium Moisture Content of Cassava

Table 6. Relative Humidities Produced by Saturated Salt Solutions

Salt	Temperature °C					
	0	15	30	45	60	75
$LiCl\ H_2O$ (Lithium Chloride)	13.5	13.0	12.0	11.5	10.5	9.5
$M_gCl_2\ 6H_2O$ (Magnesium Chloride)	35.5	34.0	32.7	31.5	30.0	29.0
$Na_2Cr_2O_7$ (Sodium Dichromate)	61.5	57.0	52.5	48.0	43.5	39.0
NaCl (Sodium Chloride)	76.5	76.0	75.5	75.0	74.5	74.0
K_2CrO_4 (Potassum Chromate)	87.6	86.7	86.0	85.0	84.0	83.5
K_2SO_4 (Potassium Sulfate)	99.0	98.0	96.5	95.0	94.0	92.5

Source: Hall, 1957

jars with potassium salt solutions, and errors in the relative humidities values.

4.7 Product Quality

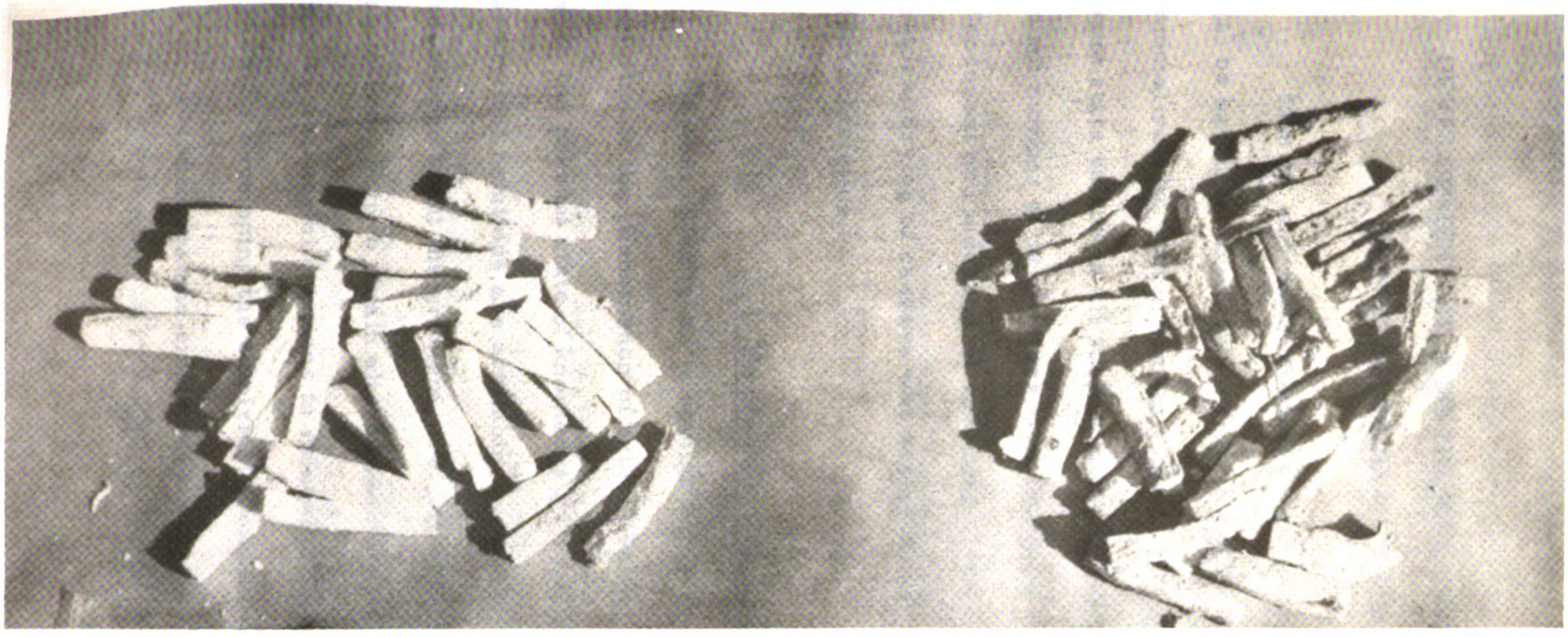
Deterioration of cassava roots after harvesting largely depends on the degree of mechanical damage incurred during the harvesting. Slicing or chipping of the roots constitute a multiple process and deterioration becomes visible in less than twelve hours in the non-treated

products. Current research on storage of the fresh product (CIAT, 1973a) indicates that retardation of deterioration is obtained by dipping the sliced roots in alcohol solutions. Dehydration to a critical moisture content within a day is one way to avoid the deterioration during the subsequent natural drying days. The critical moisture value is higher when the product surfaces are sterilized.

During the natural drying experiments subjective observations were made for signs of product deterioration such as loss of white color and smell of fermenting odor. The change of color criteria (Figure 23), was chosen because this is also a Thai quality criterion (Standards, 1966) for exporting cassava chips. More precise objective methods of product deterioration are recognized in the literature.

It was established (using the subjective criterion) that cassava particles do not deteriorate during the first three days after cutting if their moisture content reduces to 50 percent w.b. during the first drying day. This criterion is valid within the temperature range under which the experiments were performed, i.e. between 20 to 35 °C. It is also assumed that drying started inmediately after slicing or chipping, and that the roots were in a normal state of naturity , i.e. between 9 to 18 months. Dipping of the particles in a 50 percent alcohol solution for two minutes raised the critical moisture content to 54 percent.

The development of the relationships between all measured variables is the objective of the next chapter.



CASSAVA RECTANGULAR BARS

DRIED BY NATURAL CONVECTION

ON WIRE TRAYS 30 CM

ABOVE THE FLOOR

Tests 1 & 3

Aug 31, Sept 1,
Sept 2, 1972.

CASSAVA RECTANGULAR BARS

DRIED BY NATURAL CONVECTION

ON WIRE TRAYS

ON THE FLOOR

Figure 23. Quality Deterioration in Natural Drying

V DEVELOPMENT OF A METHEMATICAL MODEL OF NATURAL DRYING OF CASSAVA THICK LAYERS

Ideally, any mathematical model in applied engineering should (a) be based on sound scientific principles, (b) compare with experimental results with minimum errors, (c) be applicable to predict true state values in all ranges of the variables, (d) include the minimem number of parameters, and (e) allow explicit solution for the dependent and independent variables of the model. The data from natural drying of cassava was analyzed with a model based on these characteristics.

5.1 Empirical Drying Equation

It was established in section 2.7.2 that no rigurous analytical solution to the phenomenon of natural drying of cassava can be obtained with the present state of knowledge.It was also explained that when no analytical solutions are available, empirical formulations based on the knowledge about the problem, i.e., the known governing differential equations, help to obtain alternative forms for solutions. Furthermore, successful solutions to related problems usually provide guidelines for developing the empirical formulation.

The theories and empirical equations on drying and evaporation

(section 2.7), together with the preliminary results of section 4.3.4, suggested simple formulations for correlating all variables of importance in natural drying of cassava.

The following equation was obtained

$$\frac{dM}{dt} = -\left[M - M_{eq}\right]\left[a_0 + a_1 u + a_2 (e_s - e_a) M + a_3 (e_s - e_a)\right] \times \left[a_4 + a_5 D\right] \times \left[a_6 + a_7 P + a_8 S\right] \qquad (5.1)$$

where $\frac{dM}{dt}$ is the drying rate, M the moisture content, M_{eq} the equilibrium moisture content, u the wind velocity, $(e_s - e_a)$ the water vapor pressure deficit, D the initial load (density), P the void space fraction (porosity), and S a geometric variable given by the expression (See equation 2.5):

$$S = \frac{1}{L^2} + \frac{1}{W_1^2} + \frac{1}{W_2^2} \qquad (5.2)$$

where L, W_1 and W_2 are the dimensions of the rectangular bars.

Equation (5.1) expresses the drying rate as proportional to (a) the average drying state of the layer, (b) a combination of the ambient variables affected by the average moisture content of the layer, (c) a function of the layer density, and (d) a function of the geometrical properties.

Equation (5.1) was found to correlate equally well (section 6.1) for all the drying systems (Tables 4 and 9) when the equation was

applied individually to each one of them. The geometrical properties factor in the right-hand side of equation (5.1) was fixed at one for those systems in which the geometrical dimensions were not varied.

The equilibrium moisture content (M_{eq}) values were calculated by using an empirical equation. The equation is presented in the next section. The coefficientes $a_0, a_1, \ldots\ldots a_8$ do not have physical meaning due to the empirical character of equation (5.1). Their units are, consequentely, immaterial. The method of estimation of the coefficients is discussed in the following sections.

5.2 Equilibrium Moisture Content

The hygroscopic data was fitted to the empirical equation:

$$M_{eq} = (p_0 + p_1 RH + p_2 RH^2) \exp\left[(q_o + q_1 RH + q_2 RH^2 + q_3 RH^3) T_{abs}\right] \tag{5.3}$$

where M_{eq} is given in percentage, d.b., RH in decimal and T_{abs} in °K.

The problem of finding the best values of the coefficients $p_0, p_1, \ldots\ldots\ldots q_0, q_1, \ldots$, (in order to minimize the differences between the experimental and calculated values) is a typical case of non-linear estimation of paremeters (Beck, 1972). Non-linear least squares techniques are used to find the minimum of the sum of the squares (SS) of the differences between the experimental points (Y_i) and the calculated

values ($\hat{Y}_i$).

$$SS = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \qquad (5.4)$$

The objective function (SS) is minimized by trial and error procedures in which all the coefficients are varied systematically until the minimum of the function is obtained (Aoki, 1971). The coefficients can be estimated simultaneously if the first derivatives of the objective function with respect to the coefficients (sensitivity coefficients) are linearly independent over the range of the independent variables (Beck, 1972). Initial estimates of the coefficients are always necessary. A poor selection of the initial estimates of the coefficients might cause a slow convergence, a convergence to a local minimum instead of the global minimum or no convergence at all (Aoki (1971). The complexity of the function SS and the speed of the calculating machine will also determine the time of convergence.

The coefficients of equation (5.3) were estimated by a different method because of the limited computing facilities available at the site of the analysis, Cali, Colombia . The results were found to be not significantly different from those obtained by using a non-linear weighted estimator (Dye and Nicely, 1971) , as described in section 6.4.

The first fitting procedure consisted of estimating first the coefficients p_0, p_1, p_2 for one representative isotherm using a standard

package polynomial least squares computer program, specificaly written for an 1130 IBM digital computer. The original equilibrium moisture content data were modified because of the incorrect results obtained from the mold particles above the potassium salt solutions. The modification had the objective of weighting the data in form equivalent to the relative variance method of weighted least squares (Beck, 1972).

Equation (5.3) was transformed to the form:

$$\ln\left[\frac{M_{eq}}{p_0+p_1RH+p_2RH^2}\right] = q_0 + (q_1+q_2RH+q_3RH^2+q_4RH^3)T_{abs} \quad (5.5)$$

which represents a system of (nxm) linear equations, where n and m are respectively the number of temperature and relative humidity measurements. A standard multiple linear regression routine specifically written for the IBM 1130 computer was used to estimate the q_i parameters. The q_0 coefficients can be eliminated from equation (5.3) by multiplying the expression by the constant term $\exp(q_0)$. The equation was not simplified, however, because the coefficiente q_0 was a result of the regression analysis.

Testing of the same expression (5.3) was performed for hygroscopic data of rice (Anon.), coffee and corn (Teter and Citelly, 1970). Estimated parameters for each crop are presented in Table 7. The resulting curves and the data points are shown in Figure 24. The results are adequate for practical applications and the procedure to

fit hygroscopic data can be readily utilized in places with limited computing facilities.

Table 7. Hygroscopic Coefficients for Different Crops

Coefficient	CROP			
	Corn	Rice	Cassava	Coffee
p_o	1.3217	5.3026×10^{-1}	8.4152	3.1494
p_1	3.2477×10^{1}	4.4147×10^{1}	-5.925×10^{-1}	5.1034
p_2	-4.5483×10^{1}	-7.7246×10^{1}	3.2923×10^{-2}	3.8480×10^{1}
p_3*	3.6018	5.4161×10^{1}	0.0	0.0
q_0	2.9166	1.6187	2.4055	7.1749
q_1	-9.4119×10^{-3}	-5.0535×10^{-3}	-1.1952×10^{-2}	-2.6841×10^{-2}
q_2	0.0	-8.2358×10^{-3}	2.2138×10^{-2}	2.0752×10^{-3}
q_3	0.0	3.0469×10^{-2}	-3.7224×10^{-2}	0.0
q_4*	0.0	-4.0787×10^{-2}	2.4825×10^{-2}	0.0
q_5	0.0	1.8058×10^{-2}	0.0	0.0

* p_3 and q_4 are the coefficients of RH^3 and RH^4, respectively, in the generalization of equation (5.3).

The coefficients p_i and q_i of equation (5.3), applied to cassava, were also estimated by using a non-linear weighted least-squares method (Dye and Nicely, 1971). The experimental data were weighted as an inverse function of the estimated variances of the moisture content values.

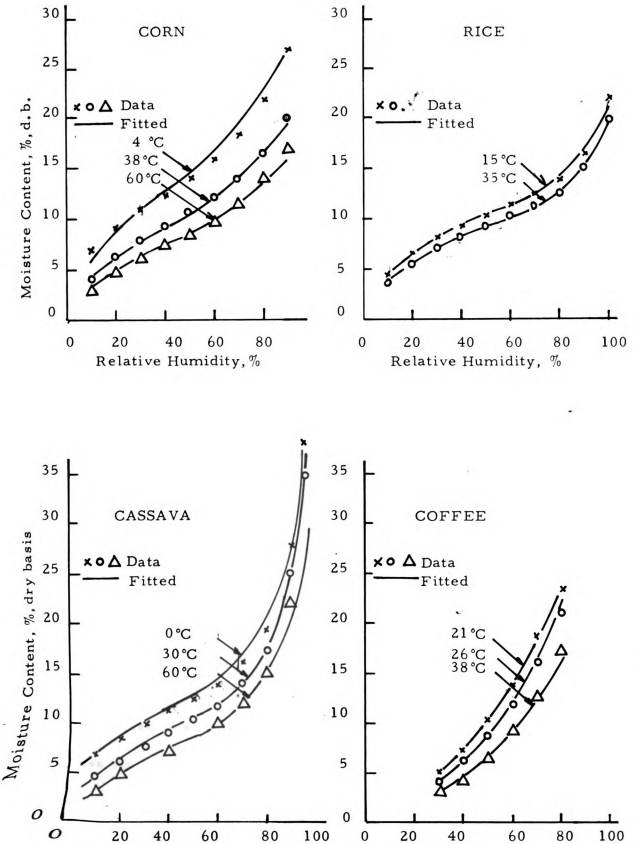


Figure 24. Equilibrium Moisture Content for some Crops.

Higher variances were given to the high moisture values. Sensitivity analysis was used to eliminate unnecesary parameters (Beck, 1972). The resulting equation was

$$M_{eq} = \left[665.707RH - 1261.97RH^2 + 622.394RH^3\right] \exp\left[(-.0085RH + .01055RH^3)T_{abs}\right] \tag{5.6}$$

The weighted, non-linear parameter estimation method presents, at least, three advantages with respect to the linear-polynominal method previously described : (a) three coefficients were eliminated, (b) M_{eq} is forced to zero when RH is equal to zero (as is required for physical reasons), (c) the data can be weighted in a more scientific manner. Comparisons of the models (5.3) and (5.6) for temperatures of 0 and 75°C are presentented in Figure 22.

5.3 Estimation of parameters in Drying Equation

5.3.1 Environmental Variables

The coefficients $a_0, a_1, a_2, \ldots, a_8$ of equation (5.1) can be estimated simultaneously using a non-linear least-squares routine, as was discussed in section 5.2. The problem is more involved, however, because the parameters appear in a non-linear differential equation, in which several independent variables are discrete functions of time. Numerical integration should be used to solve for the moisture values, which are utilized to form the objective function. The estimation problem

is handled by coupled integration and minimization routines (Dye and Nicely, 1971).

A different, but precise, solution was utilized in this study due to the limited computing facilities ar the site of the analysis. The estimation procedure was made in three stages. Data was selected in such a form that the density and the geometrical properties of the products were fixed. The third and fourth factors of the right hand side of equation (5.1) were made equal to 1 in the first stage of the estimation. The drying rates were approximated by the finite expresions :

$$\frac{dM}{dt} = \frac{M_{i+1} - M_i}{\Delta t} \tag{5.7}$$

and

$$\bar{M} = \frac{M_{i+1} + M_i}{2} \tag{5.8}$$

the resulting linear equation (in the parameters) is

$$\overline{K'} = a_0 + a_1\bar{u} + a_2(\bar{e}_s - \bar{e}_a)\bar{M} + a_3(\bar{e}_s - \bar{e}_a) \tag{5.9}$$

Experimental $\bar{K}'$values were calculated using equation (4.1) each two consecutive hourly moisture content measurements. Equation (5.3) was used to calculate the equilibrium moisture content corresponding to the average temperature and relative humidity values for the elapsed hour. Two FORTRAN subroutines, EQEQ and KEXP (listed in Appendixes A1, A2), were written to calculate the equilibrium data and the dependent variable $\bar{K}'$.

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The values of the independent variables $\bar{u}, (\bar{e}_s - \bar{e}_a)\bar{M}, (\bar{e}_s - \bar{e}_a)$ were the average hourly values which corresponded to the same hour for which $\bar{K}'$ was calculated. The water vapor pressure deficit $(\bar{e}_s - \bar{e}_a)$ values were calculated using the average temperature and relative humidities and the psychrometric model of Brooker (1970), using a set of FORTRAN functions and subroutines by Lerew (Bakker-Arkema et al., 1974) and adapted to the IBM 1130 computing system. The subroutine for calculating the saturation water vapor pressure deficits (VPDIF) is included in Appendix A3. The moisture content value in the term $a_2(\bar{e}_s - \bar{e}_a)\bar{M}$ was aproximated by equation (5.8).

An ordinary (unweighted) linear least square estimation technique, written as a FORTRAN package for the IBM 1130 computing machine, was used for estimating the coefficients. The procedure was applied to data of nine drying systems. Differences in systems were attributed to various forms of drying (relative position of the layer and the floor) or to different geometric forms (Table 8). Results of the estimated coefficients and associated statistical figures are presented in Table 9.

The estimated parameters are divided by the standard errors (Draper and Smith, 1966) to obtain the calculated t values (Table 9). Calculated t values marked with a double asterisk (**) and a single asterisk (*) indicate that the parameters were significantly higher or lower than zero at a level of 0.1 and 0.05 respectively. This is

Table 8. Characteristics of the Nine Drying Systems

Drying System	Number Observ.	Description Drier Syst.	Geometric Form	Density (kg/m^2)
1	66	vert.tray	1x1x5 cm	24
2	27	hor. tray	1x1x5 cm	24
3	67	vert.tray	disc bars	24
4	54	horiz.tray	disc bars	20
5	44	vert.drier	disc bars	26
6	61	vert.drier & wings	disc bars	26
7	13	hor.tray	large chips	12
8	6	hor.tray	small chips	16
9	18	on the floor	1x1x5 cm	20

a result of comparing the calculated t values with one-sided t statistics at the corresponding degrees of freedom. (Steel and Torrie, 1960). The multiple correlation coefficient and the F values (Draper and Smith, 1966) were compared with corresponding values of standard statistical tables with the appropiate degrees of freedom. Single and double asterisks indicate the adequacy of the model (Steel and Torrie, 1960). The test statistics were particularly useful in developing the empirical model.

No t values were calculated for the a_o coefficients because the routine utilized did not provide this option. Some of the regression

Table 9. Ambient Coefficients and Associated Statistics

Drying System	Number Observ.	Estimated Parameters	Stand. Error	Calc.t Value	Mult. C.C.	F value
1	66	a_0 = 0.0476	-	-		
		a_1 = 0.0181	0.0044	4.112**		
		a_2 =-0.0023	0.00049	-4.688**	0.708**	20.85**
		a_3 = 0.0075	0.00122	6.132		
2	27	a_0 =-0.0026	-	-		
		a_1 = 0.0119	0.00326	3.631**		
		a_2 =-0.0018	0.00046	-3.914**	0.881**	26.71**
		a_3 = 0.0069	0.00087	7.889**		
3	67	a_0 =-0.0138	-	-		
		a_1 = 0.0248	0.00515	4.812**		
		a_2 =-0.0051	0.00051	-9.978**	0.939**	155.7**
		a_3 = 0.0131	0.00083	15.812**		
4	54	a_0 =-0.0046	-	-		
		a_1 =-0.0011	0.00272	-0.366		
		a_2 =-0.0022	0.00039	-5.464**	0.947**	144.74**
		a_3 = 0.0086	0.00057	14.895**		
5	44	a_0 =-0.0023	-	-		
		a_1 = 0.0535	0.00767	6.975**		
		a_2 =-0.0044	0.00101	-4.347**	0.905**	60.23**
		a_3 = 0.0101	0.00133	7.527**		
6	66	a_0 = 0.0178	-	-		
		a_1 = 0.0144	0.00978	1.473*		
		a_2 =-0.060	0.0112	-5.369**	0.774**	28.40**
		a_3 = 0.0128	0.0175	7.277**		
7	6	a_0 = 0.0702	-	-		
		a_1 = 0.0330	0.01705	1.935		
		a_2 =-0.0007	0.00269	-0.268	0.957**	6.74
		a_3 = 0.0010	0.00214	0.449		
8	13	a_0 = 0.1279	-	-		
		a_1 = 0.0475	0.00929	5.114**		
		a_2 =-0.0022	0.00077	-2.804	0.96**	35.41**
		a_3 = 0.0017	0.00082	2.02*		
9	18	a_0 = 0.0077	-	-		
		a_1 = 0.0417	0.02272	1.836*		
		a_2 =-0.0009	0.00089	-1.022	0.641	3.26
		a_3 = 0.0026	0.00162	1.580		

coefficients of systems 4, 7, 8 and 9 were not significantly different from 0 at level of 0.01 because, most likely, of the small number of degrees of freedom. The confidence intervals for these coefficients were relatively imprecise.

The average coefficient of determination R^2 was 0.72.

$$R^2 = 1 - \frac{\sum (Y_i - \hat{Y}_i)^2}{\sum (Y_i - \bar{Y})^2} \qquad (5.10)$$

where Y_i represent experimental $\bar{K}'$ values calculated by equation (4.1), $\hat{Y}_i$ the $\bar{K}'$ values calculated using equation (5.9), and $\bar{Y}$ the average Y_i values. This analysis indicates that 72 percent of the changes in $\bar{K}'$ were explained by the linear model. The remaining 28 percent should be attributes to (a) improper model, and (b) to stochastic errors which occurred in the field measurements.

A discussion of the results of the regression analysis is aided by writing the model in the form

$$\bar{K}' = a_0 + a_1 + a_2 (e_s - e_a) M + a_3 (e_s - e_a) + \epsilon' + \epsilon'' \qquad (5.11)$$

where ϵ' represents the errors due to the lack of fit of the model and ϵ'' refers to pure errors which might be listed in a suggested order of importante as follows : (a) measured errors in the dependent variable $\bar{K}'$ (Figures 16 and 17) due to slow drying responses with respect to the average ambient changes, (b) weighing errors due to losses of the product in the form of "fines" during the experiments and during the dry

matter content determination, (c) errors of the different drying effects due to wind direction, not accounted for in the measurements, (e) errors caused by measurements made at intervals different from the fixed one hour interval, (f) errors due to non-homogeneous cassava product, (g) errors due to the inaccuracy of the M_{eq} model, (h) human errors in taking the measurements, and (i) errors of calibration and accurary of the instruments.

These errors violate some of the standard assumptions made in the ordinary least squares estimation with respect to the value of the estimated parameters and the statistical tests (Kmenta, 1971). The least squares assumptions and a brief analysis of the violations are:

1. Homoskedasticity, which states that the variance of the errors is constant $\left[\text{expected } (\epsilon_i^2 = \sigma^2)\right]$, did not strictly apply because the experimental errors were known to be higher at low moisture content values, when the difference $(M - M_{eq})$ approximated zero and when more "fines" were lost.

2. Nonstochasticity of the independent variables $\left[\text{expected } (x_i) = x_i\right]$ was slightly violated by the time measurement errors.

3. Non-autoregression $\left[\text{expected } (\epsilon_i \, \epsilon_k) = 0\right]$ for different measurements i and k. This assumption, also known as errors correlated, errors not-independent, etc., (Beck, 1972), did not apply. Cummulative errors, a particular type of correlated errors, occurred

because any loss of the product at the measurement i affected all subsequent measurements. Also a timing error made at the measurement i did cause a compensating error at time i + 1. (Figure 17).

These violations plus the assumption that the density (D) and geometrical properties (P and S) did not affect the estimation of the ambient parameters limit the value of the statistical tests regarding the estandard error, and consequentially the confidence intervals.

An alternative method of testing the value of the statistical tests and the confidence intervals was chosen in this study: the predictions of the model were compared with the experimental data in all ranges of the independent variables. The tests are described in the first section of Chapter VI.

5.3.2 Layer Densities

The estimation of the ambient parameters assumed product uniformity in their density and equality of the particle geometry. In this section the experimental data is analyzed by fixing the geometrical variables only. The fourth of the right-hand side of equation (5.1) was fixes to 1 . Under these assumptions, equation (5.1) can be written in its finite form as

$$\bar{K}" = a_4 + a_5 D \qquad (5.12)$$

where

$$\overline{K''} = \frac{\overline{K'}}{a_0 + a_1\bar{u} + a_2(\bar{e}_s - \bar{e}_a)\overline{M} + a_3(\bar{e}_s - \bar{e}_a)} \qquad (5.13)$$

$\overline{K'}$ values were calculated by equation (5.9). The new parameter estimation problem (equation 5.12) is one of simple linear regression. Partial information of the imput data is summarized in Table 10. The results are shown in Table 11. All the test statistics were shown to be significant at the 0.01 level.

Two observations are worth noting: (a) the simplicity of the density linear factor does not mean that there exists a linear relationship between the drying rates and the layer density because of the moisture content depending term in the right-hand side of the equation (5.1). In thicker layers, for example, the average moisture content is higher than for thinner layers, if all other conditions are equal. This weights more the $a_2(\bar{e}_s - \bar{e}_a)\,\overline{M}$ term, and the apparent linearity does not hold, (b) the linear density term was nearly the best one that could be given In effect, when a parabolic function ($a_4+a_5D + a_6D^2$) was used, no improvement in the fitting was achieved, as it is indicated by comparing the F values of Tables 11 and 12.

5.3.3 Geometric Properties

Equation (5.1) in its finite-approximation form is

Table 10 Density Characteristics for each Drying System

Drying System	Density (kg/m^2)	Number Observ.	Description Drying System	Geometrical Form
1	16	29	vertical tray	1x1x5 cm
	20	83		
	24	63		
	28	38		
		213		
2	16	22	hor. tray	1x1x5 cm
	20	94		
	24	26		
		142		
3	16	53	vertical tray	disc bars
	24	49		
	28	36		
		177		
7	12	6	hor. tray	small chips
	16	6		
		12		
8	8	6	hor. tray	large chips
	12	13		
	16	6		
		25		
9	8	18	on the floor	1x1x5 cm
	20	8		
		26		

Table 11 Density Coefficients and Associated Statistics

Drying System	Estimated Coefficient	Standard Error	Calculated t value	Mult, C. Coeff.	F value
1	a_4=1.5396	-	-		38.5**
	a_5=-.0221	.0357	-6.205**	.393**	

Table 11 Density Coefficients and Associated Statistics (Continued)

Drying System	Estimated Coefficient	Standard Error	Calculated t value	Mult. C. Coeff.	F value
2	a_4=2.3996 a_5=-.0615	- .0891	- -6.890**	.504**	47.59**
3	a_4=1.5585 a_5=-.2526	- .0405	- -6.233**	.426**	38.85**
7	a_4=3.2536 a_5=-.1409	- .0226	- -6.238**	.892**	38.92**
8	a_4=1.8266 a_5=-.0695	- .0056	- -12.399**	.933**	153.68**
9	a_4=2.6564 a_5=-.0838	- .0139	- -6.051**	.777**	36.62**

Table 12 Density Coefficients of a Parabolic Function

Drying System	Estimated Coefficient	Standard Error	Calculated t value	Mult. C. Coeff.	F value
1	a_4=1.7838 a_5=-.4497 a_6= .0513	- .4075 .0912	- -1.103 .562	.393**	19.35**

$$\bar{K}''' = a_6 + a_7 P + a_8 S \tag{5.14}$$

where

$$\bar{K}''' = \frac{K''}{a_4 + a_5 D} \tag{5.15}$$

S is given by equation (5.2) . The porosity of rectangular bars (Figure 21) was fitted to the equation

$$P=(0.420+0.016L)\,(1.1609-0.144W) \qquad (5.16)$$

where L is lengthof the bar and W the thickness of the square section of the bar. $\bar{K}''$ values were calculated by equation (5.13) for drying systems 1 and 2 (Table 8). During the $\bar{K}'''$ calculations no restrictions were made.

The coefficients a_6, a_7, and a_8 were estimated by ordinary multiple linear regression. Characteristics of the input data and the estimation results are given in Table 13.

The previous discussion of errors applies as well to this final stage for the estimation of parameters. In effect, all the violations to the standard assumptions that were mentioned in the previous stages are applicable to this case.

Table 13. Geometric Coefficients Characteristics and Statistics

Drying System	Number Observ.	Estimated Coefficient	Standard Error	Calc.t value	Mult. C.C.	F value
1	613	a_6=-1.0633 a_7= 1.8630 a_8= 0.5245	- 0.386 0.028	- 4.831** 18.677**	0.614**	184.8**
2	232	a_6=-0.8093 a_7= 2.6647 a_8= 0.2125	- 0.394 0.027	- 6.761** 7.912**	0.506**	39.4**

IV ANALYSIS

6.1 Comparison of Experimental and Calculated Moisture Contents

A complete testing of the mathematical model is given in this section in order to answer the questioned properties of the confidence intervals of the estimated coefficients of the model given by the equation (5.1) . An explicit moisture relationship was desirable and readily obtained by using equation (5.1) in its finite form:

$$\frac{M_{i+1} - M_i}{t} = -\left[a_0 + a_1 u + a_2(\bar{e}_s - \bar{e}_a)\left(\frac{M_{i+1}+M_i}{2}\right) + a_3(\bar{e}_s - \bar{e}_a)\right]\left[a_4 + a_5 D\right] \times \left[a_6 + a_7 P + a_8 S\right]\left[\frac{M_{i+1}+M_i}{2} - M_{eq}\right] \tag{6.1}$$

soving for M_{i+1} with $\Delta t = 1$

$$M_{i+1} = -\frac{c_1}{2c_0} + \frac{(c_1^2 - 4c_0c_2)^{0.5}}{2c_0} \tag{6.2}$$

where $c_0 = 0.5 b_1 b_2$

$c_1 = 0.5\, b_0 b_2 + b_1 b_2 b_3 + 1$

$c_2 = b_0 b_2 b_3 - M_i$

and $b_0 = a_0 + a_1 u + 0.5 a_2 (\bar{e}_s - \bar{e}_a) M_i + a_3 (\bar{e}_s - \bar{e}_a)$

$b_1 = 0.5 a_2 (\bar{e}_s - \bar{e}_a)$

$$b_3 = 0.5M_i - M_{eq}$$

A subroutine (LAYEQ), listed in Appendix A4, was programmed to perform the moisture calculations in a discrete hourly form. The single subroutine was made applicable for all drying systems by giving a selected value of one to the non-estimated parameters a_4 and a_6 and zero to the non-estimated parameters a_5, a_7 and a_8. The calculation procedures were:

1. the equilibrium moisture content and the saturation water vapor pressure deficit were calculated by the subroutines EQEQ and VPDIF as function of the given average hourly weather conditions.
2. the first moisture content values M_1 were calculated as a function of the given initial moisture content M_0, the calculated M_{eq}, the $(\bar{e}_s - \bar{e}_a)$ values, the given average value of the air velocity during the first drying hour, the product densities, and the geometric properties. The apropriate set of estimated parameters was used in equation (6.1) for the corresponding drying system.
3. the calculated moisture content values of M_1 were stored in place of M_0 to be used as the initial moisture content for the next calculations, which were performed in the same form.
4. the iterations continued until the last values of the drying day.

The main computer program performed the general comparison as follows:

1. all the information necessary to identify the drying experiment was read in.

2. field measurements were read in and some readings were corrected because of non-calibrated instruments.
3. experimental moisture content values were calculated for the second experimental period. The moisture content values corresponding to the first experimental period (calculated with the oven set at 75° C) were read in and were normalized to the moisture base corresponding to the oven used for dry matter content determination in the second experimental period (100°C).
4. the geometric properties of the bars were calculated.
5. the hourly average ambient values for each drying day were calculated.
6. subroutines EQEQ, VPDIF, and LAYEQ were called to calculate - using the model - the moisture content values for each hour.
7. experimental and calculated hourly moisture content were compared in dry and wet basis, and moisture ratio forms.
8. a last moisture content value was calculated using only average weather condition of the day and was compared with the final experimental moisture content value.
9. a comprehensive output of the results was printed.

The listing of the main program and a short example of the output are included in the Appendices A5 and A6.

A summary of the comparison results follows:

1. the particles lost a daily average of 54 percent of the total possible removable water. The standard deviation about the mean was 20.4 percent, i.e., almost all the posible range of dehydration was covered. The average recorded drying hours was 6.7 hour per day. The hourly average moisture content was 48.6 percent, w.b., the complete practical range of moisture content was recorded (70.0 to 12.0 percent, w.b.).
2. the coefficient of determination of the calculated moisture content with respect to the experimental values was 0.983 when the moisture was expressed on a wet basis. This means that the single model predicted 98 percent of the moisture content changes during the 1691 observations supplied from the 9 drying systems.
3. the hourly average moisture content error for all observation was of 2 percent, w.b.
4. the final moisture content error calculated based on the average weather condition for the drying day was 3 percent w.b. -- average value of 152 observations-- This result indicates that the enviromental conditions for each day did not vary too much.
5. the model worked equally well for the nine drying systems. The highest hourly average error was of 2.3 percent, w.b.

and corresponded to the drying system 1 (Table 8).

6. the errors seemed to present a uniform distribution within the ranges of the weather conditions, the densities and the geometric values of the drying system. The errors were slightly higher for the vertical drying systems compared to those of the horizontal ones.

7. the most severe tests of the model were the following comparisons:

   a. more than 1100 comparisons of moisture content values of drying systems 1 and 2 were made based on only 6 ambient parameters estimated from 133 observations.

   b. a hundred fifty-four comparisons of drying system 2 (Table 8) were made with an hourly average error of 1.5 percent, w.b., and average drying day of 6.4 hrs. None of the experimental values was utilized for estimating the coefficients of the model. Furthermore, more that 50 percent of these observations had densities of 8 kg/m^2, which value was not used in estimating the density coefficients.

   c. ninety-six comparison were made from data obtained at night. The hourly average moisture error was 1.6 percent, w.b. for 12 hours. The weather conditions were significantly different from the average prevailing conditions during the study. During this period a peak relative

humidity of 93 percent and an air velocity of 0.1 m/sec were recorded.

Typical comparison results are shown in Figures 25, 26, 27 and 28. Three curves are shown in each graph : (a) the experimental moisture content ratios, (b) the calculated moisture content ratios based on hourly average ambient conditions, and (c) the calculated moisture content ratios based on average daily conditions.

This summary permitted establisment of the excellent properties of the estimated coefficients of the model and their wide applicability. The violations of the standard assumptions of least squares were not strong, and the model is adequate to predict or simulate drying performances in most practical ranges of the independent variables. Simulation is one of the main objectives of the remaining sections of this chapter and the following.

6.2 Comparison of Different Natural Drying Systems

Comparison of the performances of the different drying systems can now be made. The good model and the use of average weather conditions permit these comparisons.

6.2.1 Simulation

Computer programs were written to predict or simulate drying of the nine systems under wide ranges of environmental conditions and different layer densities. A listing of the program used for six of the nine drying systems and a short output example are included in

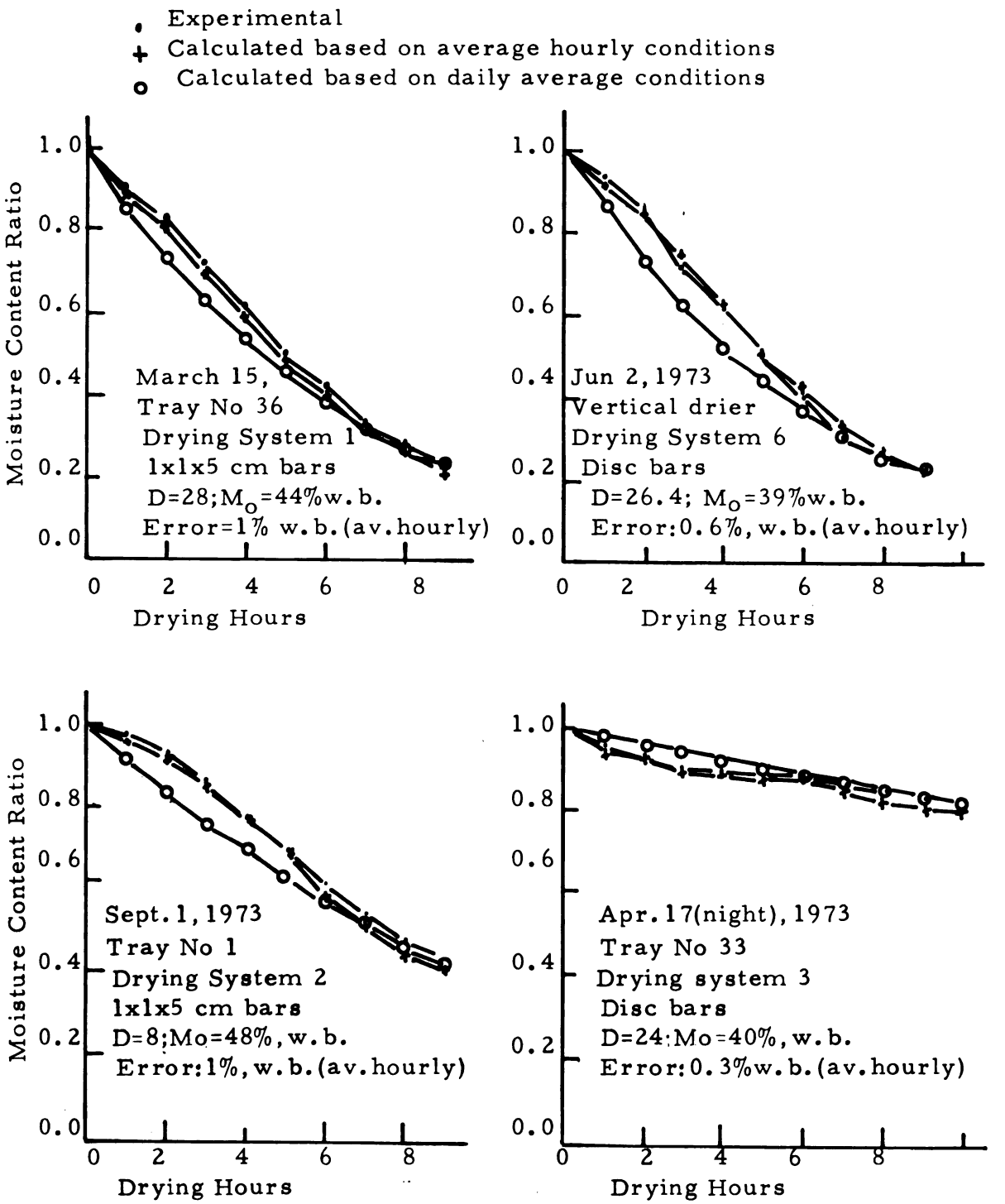

Figure 25. Comparison of Experimental and Calculated Values.

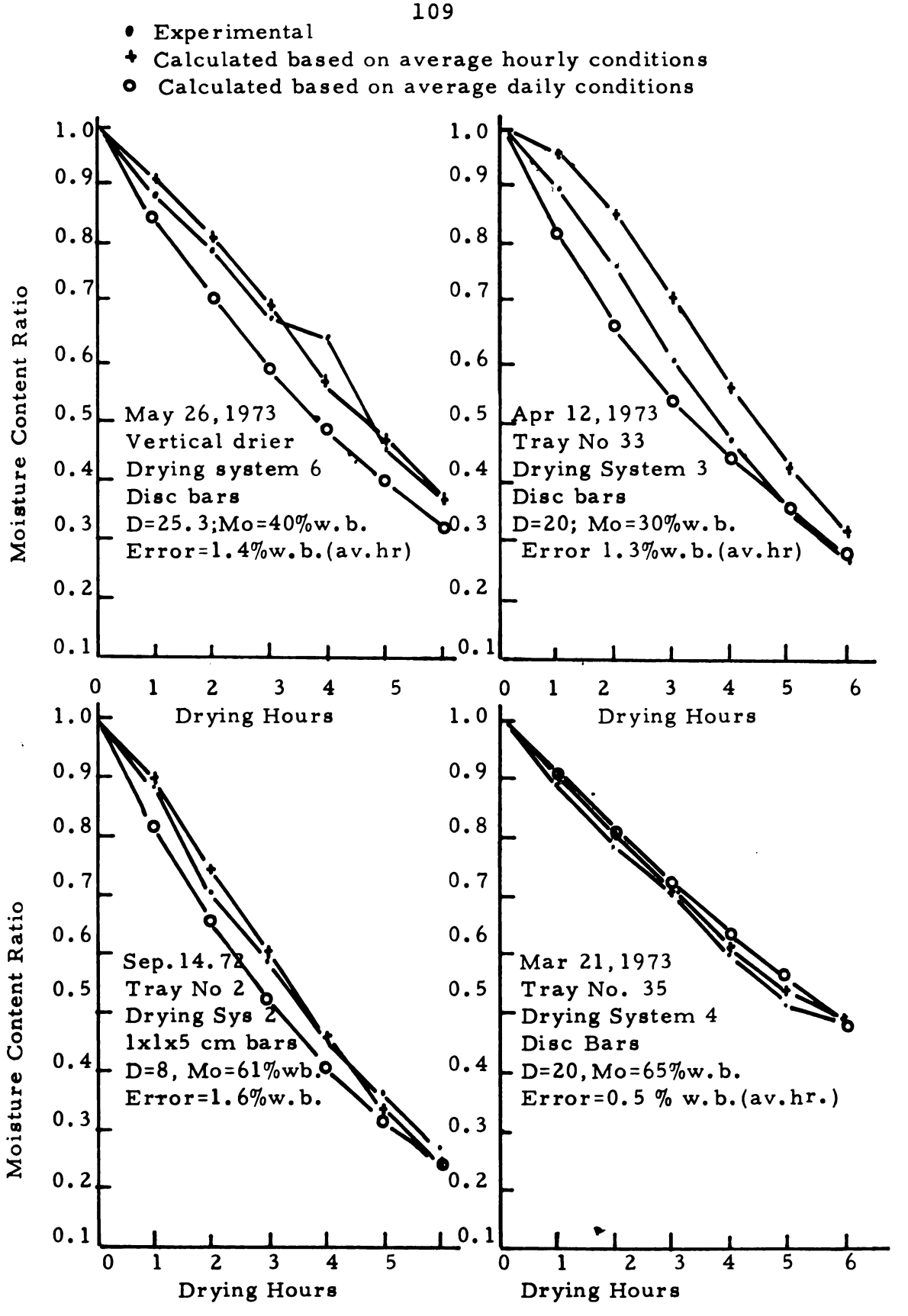

Figure 26. Comparison of Experimental and Calculated Values.

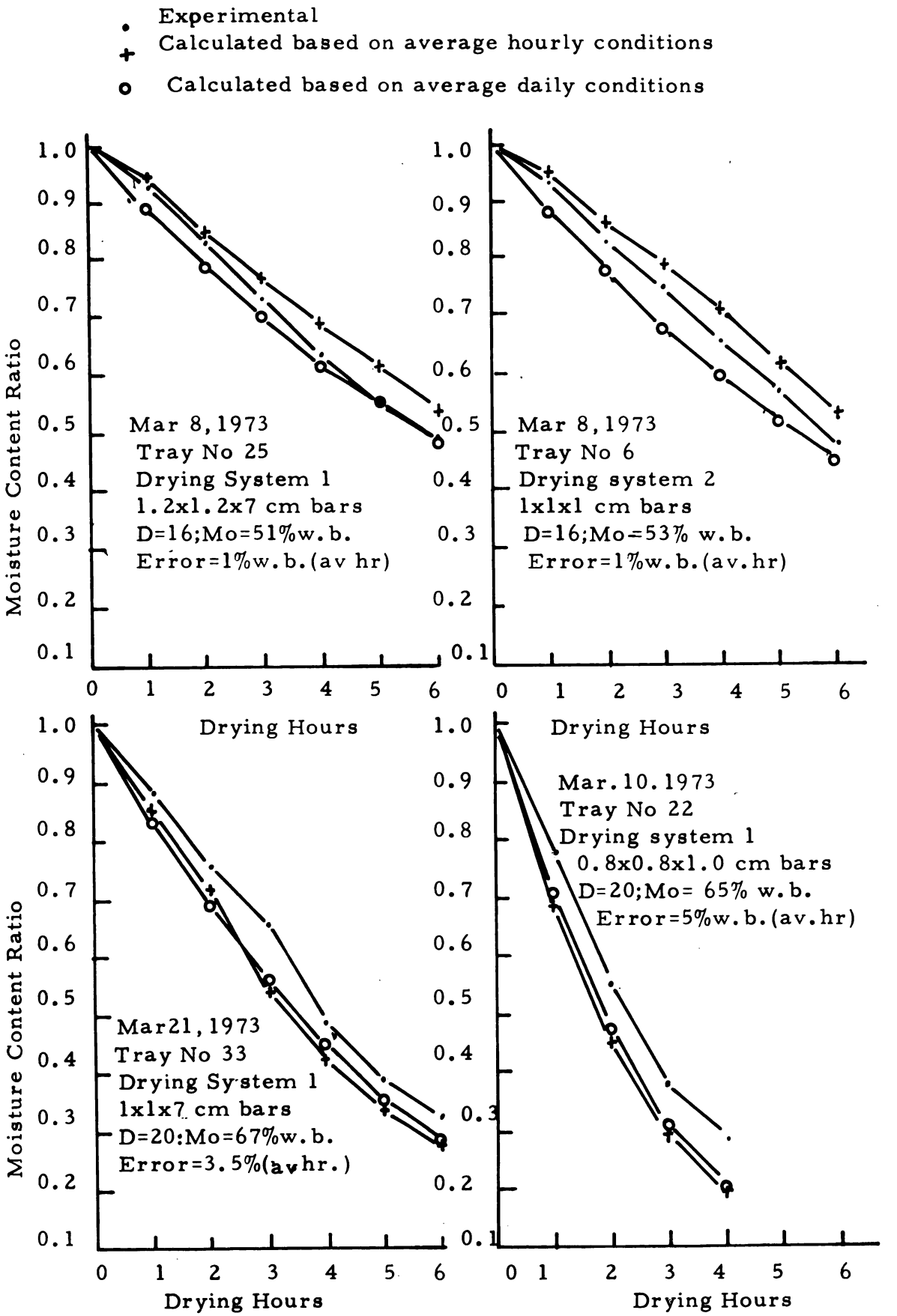

Figure 27. Comparison of Experimental and Calculated Values

Moisture Content Ratio
Moisture Content Ratio

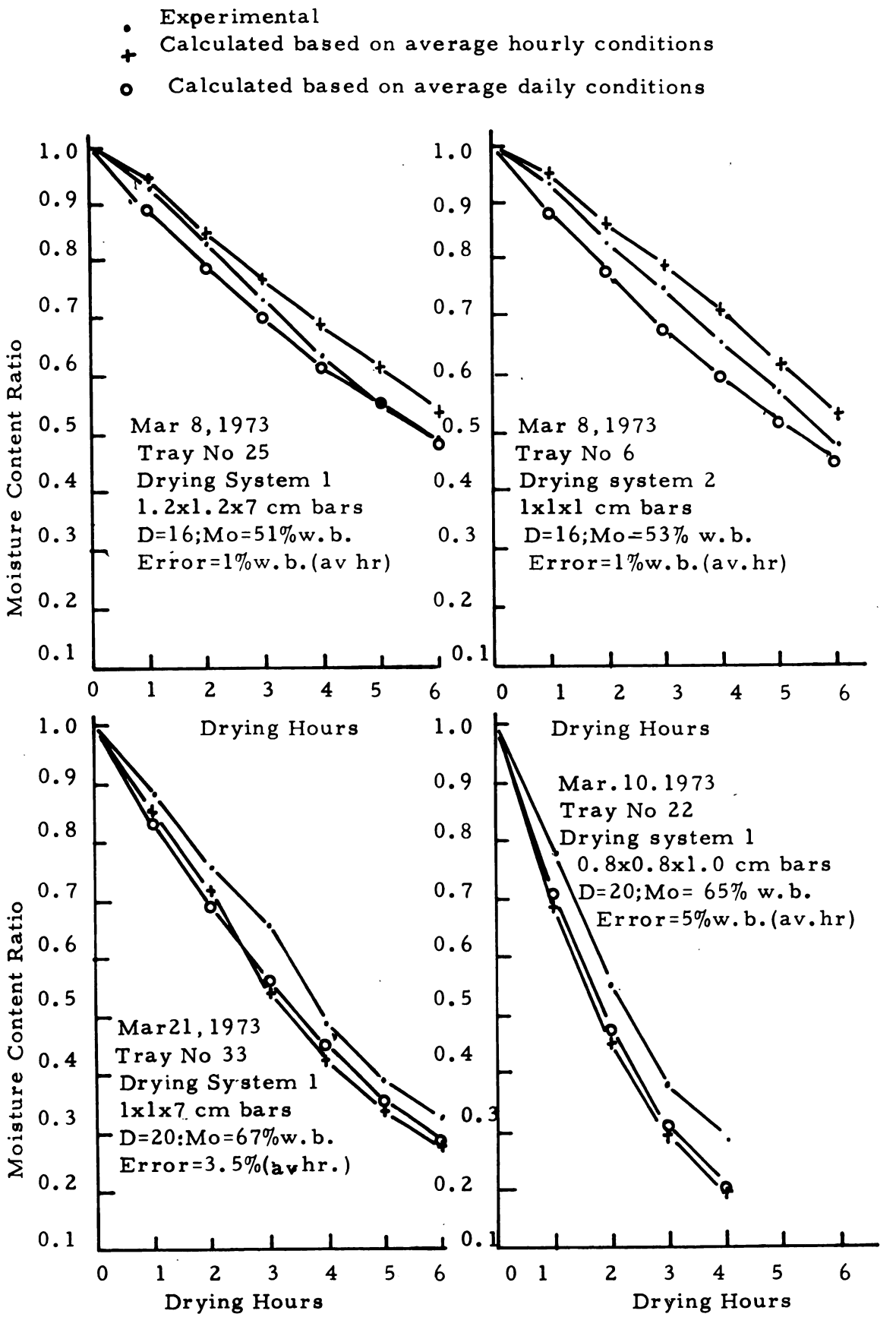

Figure 27. Comparison of Experimental and Calculated Values

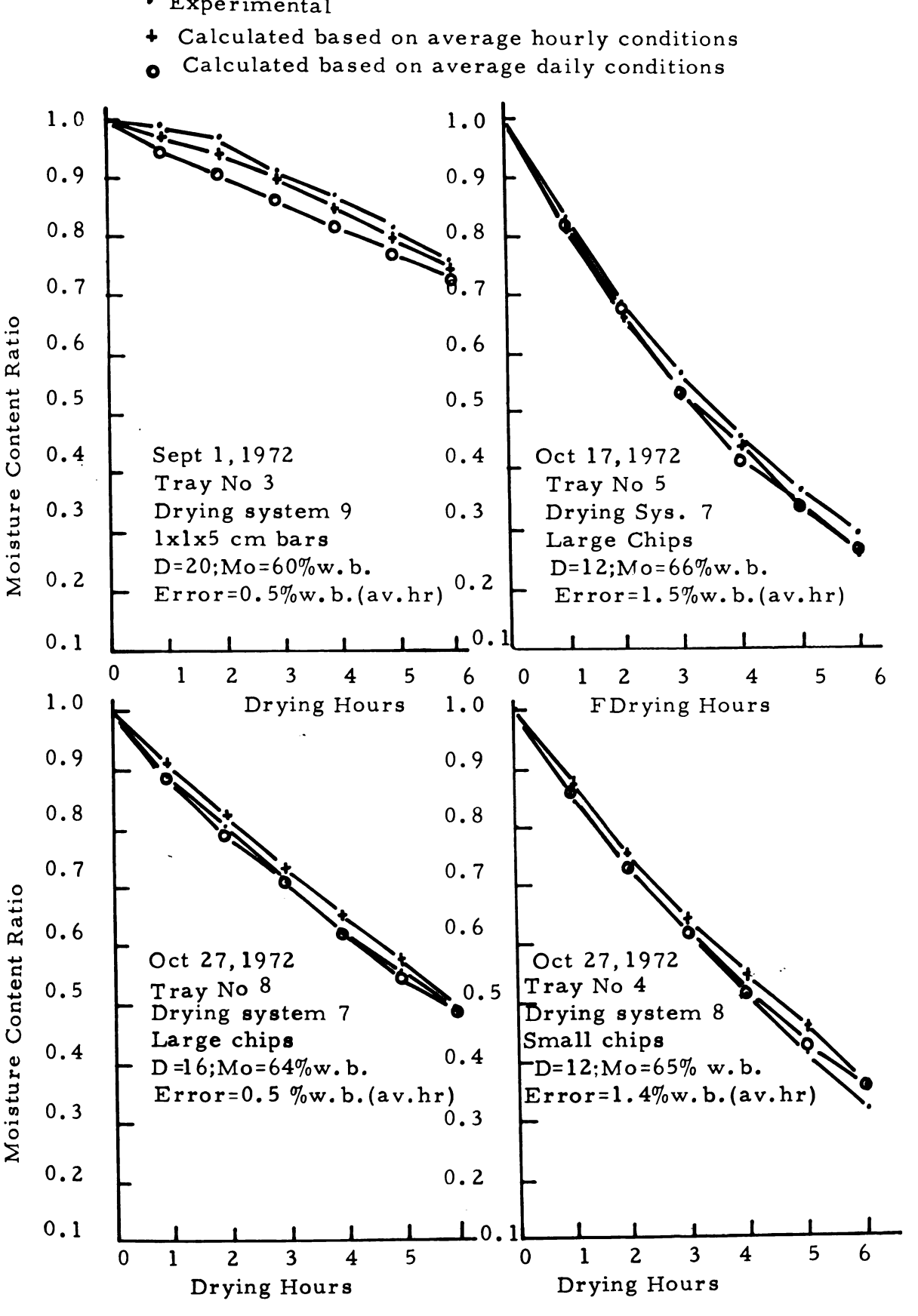

Figure 28. Comparison of Experimental and Calculated Values

the Appendices A7 and A8. The systems simulated are described by the computer listing COMMENT cards. The values given to the variables were :

density[1] : 10, 25, and 40 kg/m^2

wind velocity : 0.5, 1.5, 2.5, and 3.5 m/sec.

air temperature : 5, 15, 25, and 35°C

air relative humidity : 40, 50, 60, 70, 80 and 90 percent

Thirteen hours of a drying day were simulated for all combinations of the variables and for each system. A similar program was run to simulate all the drying systems, including those models that did not fulfil the statistical tests (section 5.3.1). Results of these models were analyzed only for the conditions in which the experiments were performed.

6.2.2 Solar Cabinets

The best performance of the solar driers is shown in Figure 13a. The solar cabinet loaded with 8 kg/m^2, removed about 4 percent more of the total removable water than the horizontal tray with the same load. Simulated results were used to compare the cabinet with a vertical tray drying under the same conditions. The comparison resulted in 4 percent higher dehydration for the vertical tray. The difference could be about 25 percent or higher if a more practical density had been used

[1] density coefficients for the vertical drier were estimated based on those of the vertical trays for the same product.

and a more common wind velocity had ocurred such as 20 kg/m^2 and 2.0 m/sec.

A simple energy balance shows the limitations of a solar cabinet that uses only incident radiation to dry high moisture content products. From the 4.24×10^6 cal/m^2 recorded radiation during 8 drying hours (Sept. 21, 1972), about 60 percent was collected by the black surface. The estimated drying efficiency of 60 percent reduces this amount to a net of 1.52×10^6 cal/m^2 . About 0.58×10^6 calories are necessary to evaporate one kilogram of water. The cabinet, based on these figures, was expected to evaporate 2.62 kg/m^2 of water during the 8 hours but actually evaporation was 3.84 kg/m^2. Simulated results indicate that a vertical tray loaded with 25 kg/m^2 and an average wind velocity of 2.5 m/sec, all other conditions equal, evaporates about 11.5 kg/m^2.

The facts that this cabinet was the best among all solar driers are explained by examining the relative position of the cassava layer between the collector and the free air underneath (Figure 12) : the 10 cm distance for the collector and the contact with the air allowed the the product to use both the collected solar energy and the sensible energy of the air. The efficiency was still very low compared with the vertical tray because the air movement was restricted.

It seems difficult to design a more efficient unit for natural drying of high moisture content products because attempts to collect the solar energy imply the restriction of the air circulation, which has

more energy available for drying the products during the early periods of the dehydration process.

The cabinet drying rates for this day and for the very small density of 8 kg/m^2 were higher than the highest drying rates for drying yams reviewed by the author: 2.8 kg/m^2 in 20 hours (Headely and Springer, 1973) and 1.2 kg/m^2 in 24 hours by Nahlawi, (1960). The drying rates of CIAT's cabinet could be increased without diminishing the product quality by just using higher densities.

6.2.3. Product on the Floor

Figure 5 shows the drying differences between cassava bars elevated from the floor in perforated trays and the same product on the floor. Figure 23 shows the quality differences of the end product for the same experiment. Figure 29a shows a similar comparison by simulation with the addition of the performance of the vertical tray with the same product. The importance of the air circulation through the product is clearly evident. Ambient conditions were chosen to match the ambient conditions of one day in which the experiment of the product on the floor was run (the statistical tests were not significant for the drying system 9, see section 5.3.1).

6.2.4 Cassava Chips

The drying characteristics of the conventional cassava chips were inferior to those of the rectangular bars as is shown in Figure 14 and

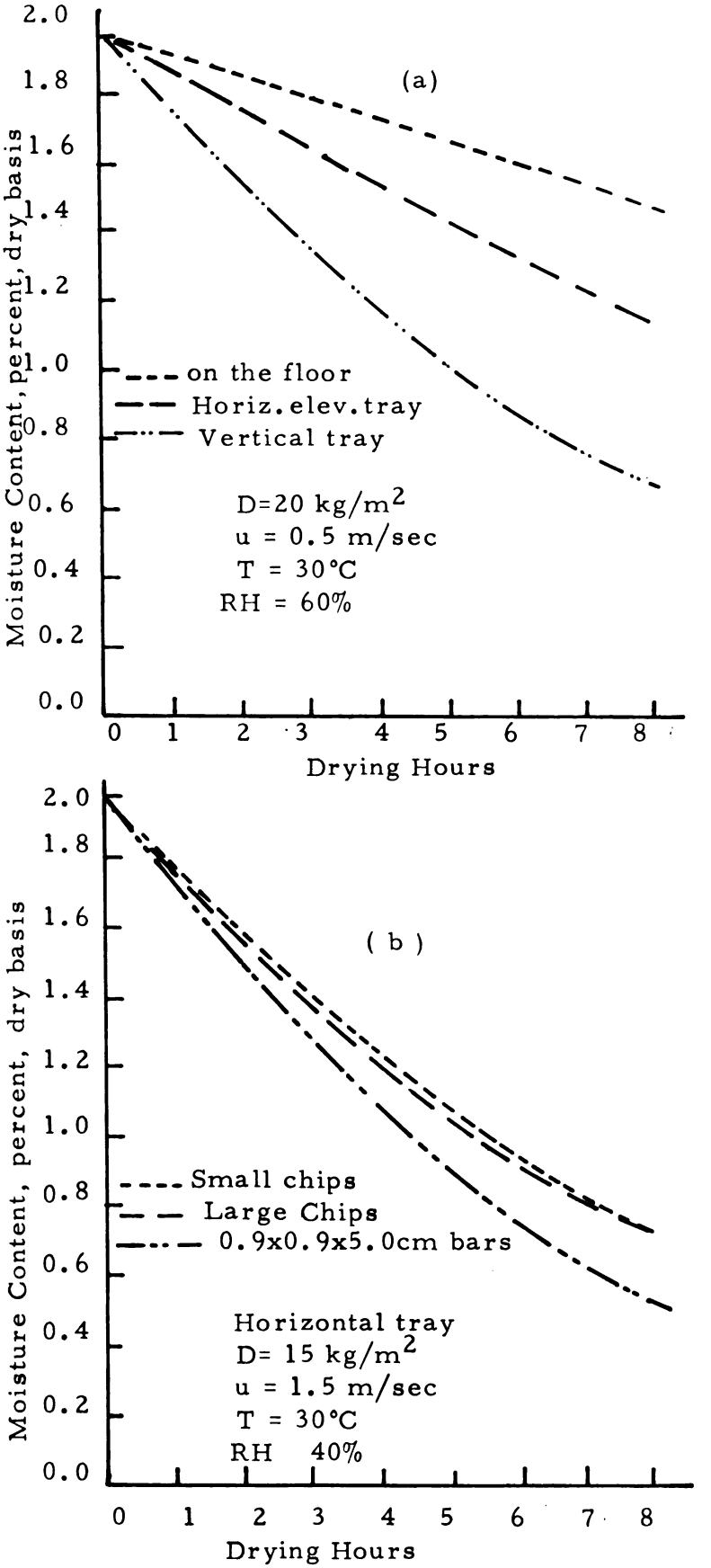

Figure 29. Comparison of Drying by Simulation.

confirmed, in a more general form, in Figure 29b. The ambient conditions chosen to make the comparison are those of a drying day of the large chips. Larger chips were slightly better than small chips for drying in thick layers because of their firmer structure and higher porosity values. (Figures 14d and 29b).

6.2.5 Disc Cutter Bars

The efforts to produce equally efficient rectangular bars with the disc as with the manual press were not succesfull as is shown in Figure 30. The manually pressed rectangular bars were consistantly superior because they permitted air to circulate more easily and because they were more uniform in size. The differences in performance are higher in vertical than in horizontal trays. Fines, the weak structure of the disc bars, and the non uniform bar's sections make them lose the desirable aerodynamical properties sought. Multiple indirect observations showed that the disc bars performed better than the conventional chips. However, no direct experimental comparisons were made, and comparisons by simulation could not be made because of the poor estimated coefficients of these models. The disc bars are analyzed only from a practical point of view in section 6.4.

6.2.6 Rectangular bars

The bars produced by the manual press were the best geometry

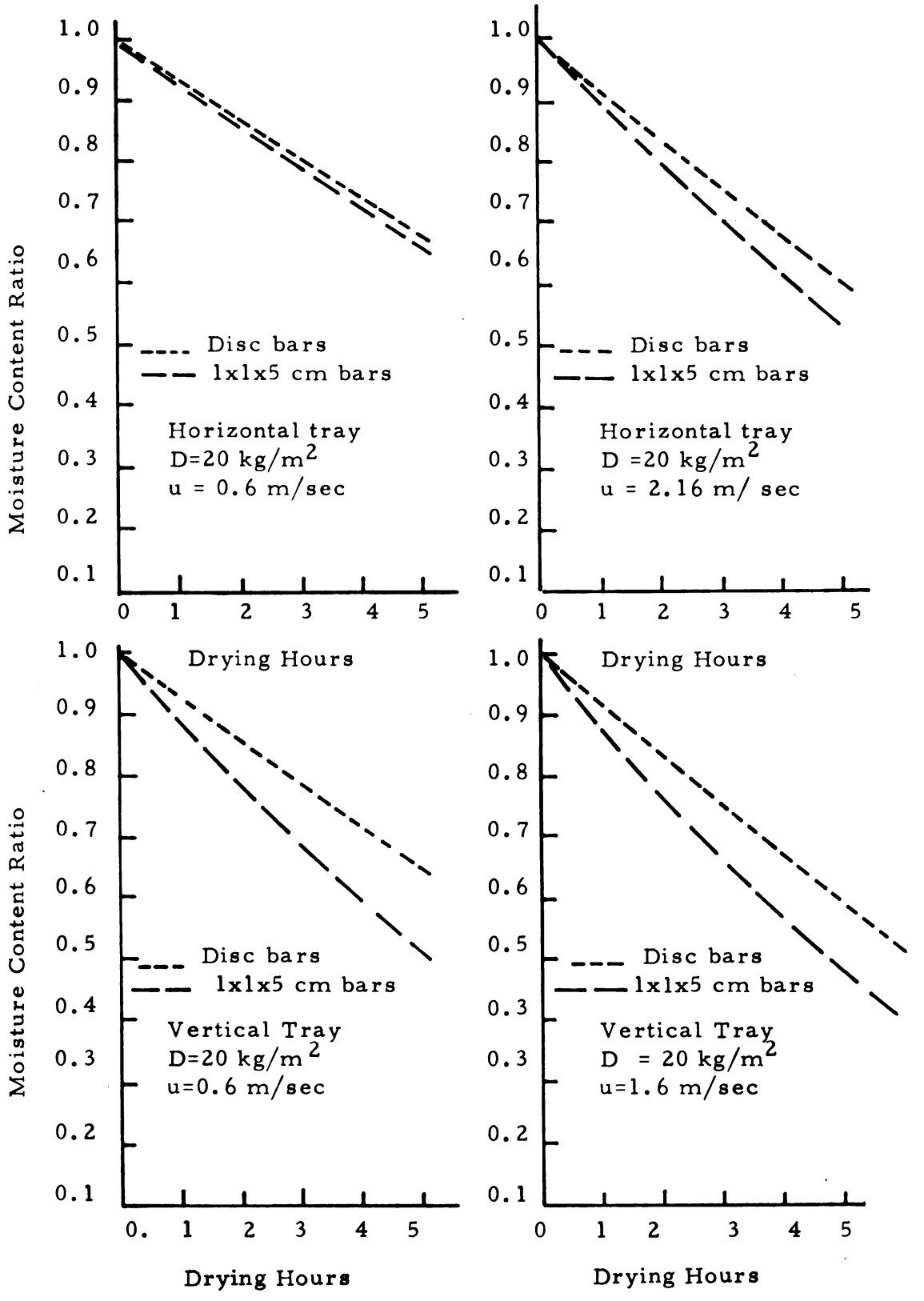

Figure 30. Comparison of bars produced by the Disc and Press

tested because of their drying characteristics, good handling properties and general appearance. Changes in the bar dimensions were very critical as is shown in Figure 31 and in the sensitivity study of the last section (6.6) of this chapter. The geometrical properties were expressed by the equation.

$$F = a_6 + a_7 P + a_8 S \qquad (6.3)$$

where the porosity P and the geometric property S are given by expressions (5.16) and (5.2) respectively. Expression (6.3) was succesfully applied in the model (6.2) for 1174 comparisons with experimental data. One way of increasing F was obtained by increasing the porosity. Higher porosities were obtained by enlarging the bars (Figure 21). No further improvement occurred after a length of 7 cm.

A more effective method to increase F was to decrease the bar dimensions. Again, practical considerations restricted the procedure: (a) there exists a critical minimum characteristic length of transition between cassava bars to cassava fines. The phenomenon is related to the critical mean free path of the natural air flow through the layer, and (b) small bars with section less than 1x1 cm can hardly be made with low-cost cutting devices. This limitation does not seem too restrictive if more sophisticated type of machinery -- like industrial dicers for fruits, roots, and vegetables -- are used (FMC, 1960).

The smallest particle tested in the study was a bar with the

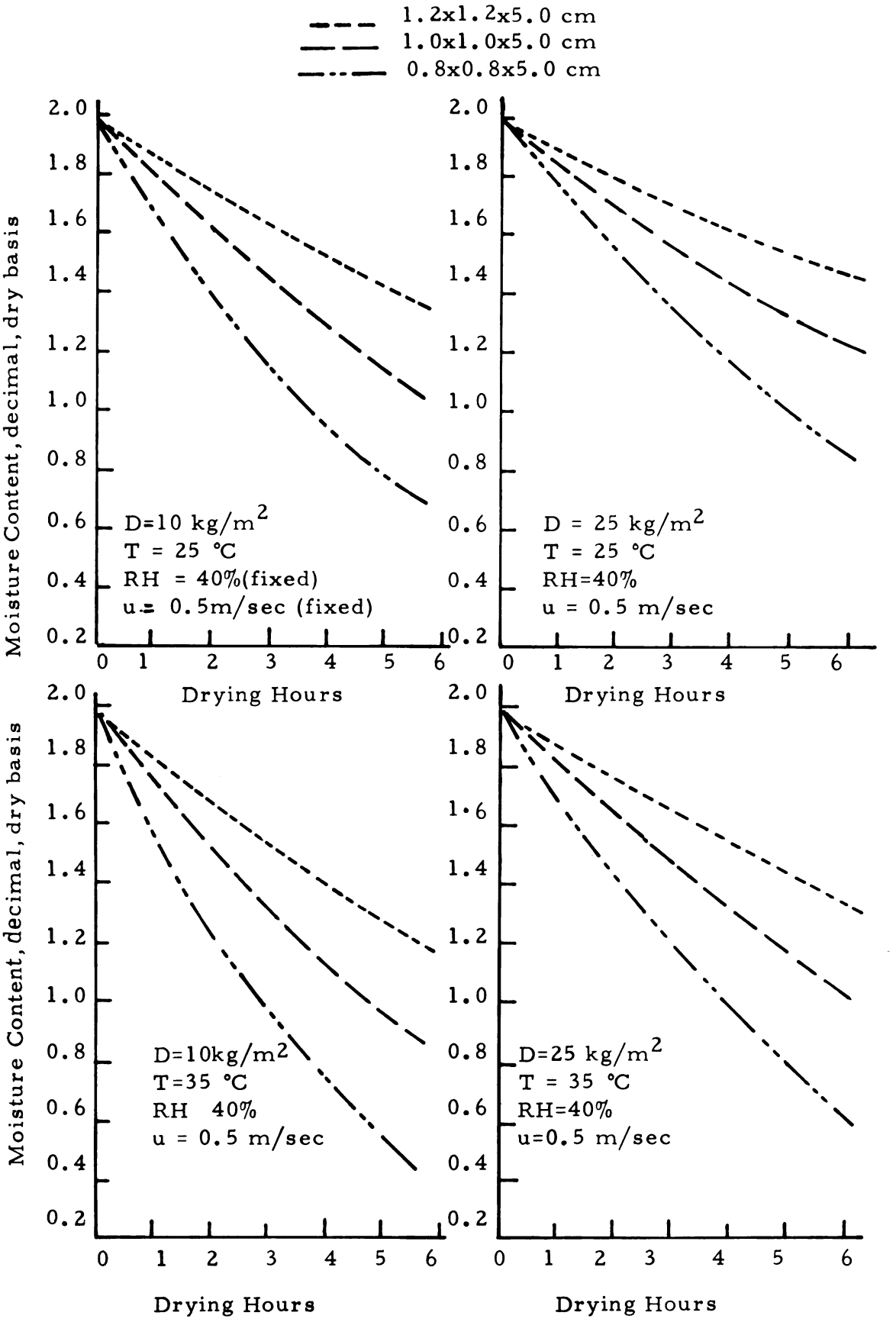

Figure 31. Comparison of Rectangular Cross Section.

dimension 0.8x8x1.0 cm (P=0.456 and S=4.125). The particles were tested in a vertical tray with D=20 kg/m^2 on March 10, 1973 (Figure 27d). This was the highest desorption rate during the study, higher than the dehydration of the black dusted particles on a good sunny day (Figure 13c). In both experiments the individual particles reached approximately the same moisture content ratio but the black cassava layer had only a density of 8 kg/m^2.

Figure 31 shows the importance of the section of the bars for two densities and for two ambient conditions.

6.2.7 Vertical Driers

The vertical drier was a commercial extension of the scaled vertical trays. Simulated performance of the two driers, together with the vertical drier modified with the wings, are shown in Figure 32. Two main conclusions can be be made from the graph: (a) the plain vertical drier has an advantage over the trays, and (b) the plain vertical drier has an advantage over the modified drier. Both conclusions are very practical because they result in reduction of cost in natural drying of cassava. The better performance of the vertical drier over the small trays can be attributed to smaller effects of the big, flat, and porous plate in changing the air current direction due to higher cohesion forces of larger air masses. Also, the larger the flat plates, the more air turbulence exists when the air flow is parallel to the plates. Higher turbulences result in

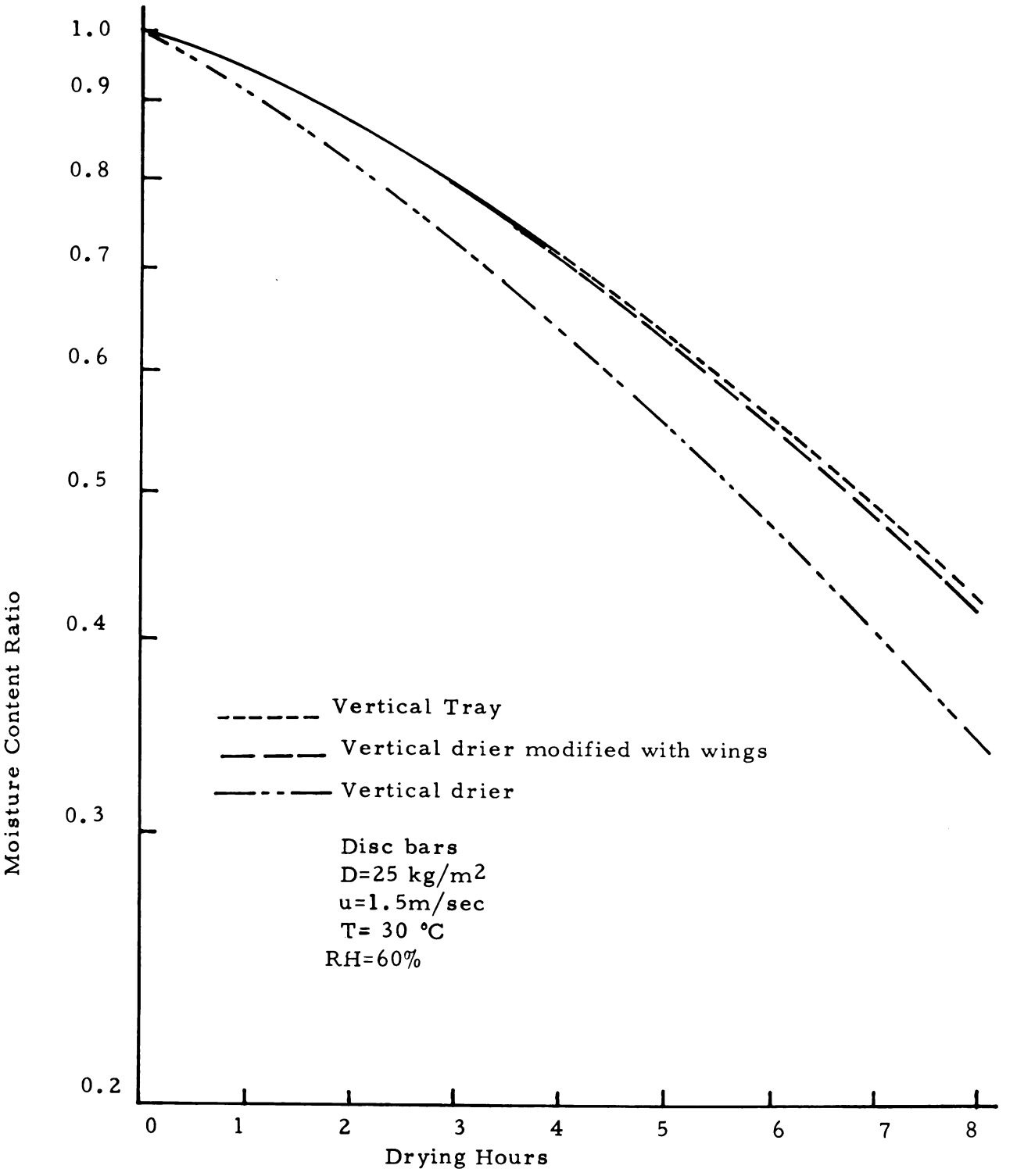

Figure 32. Vertical Drier Performances

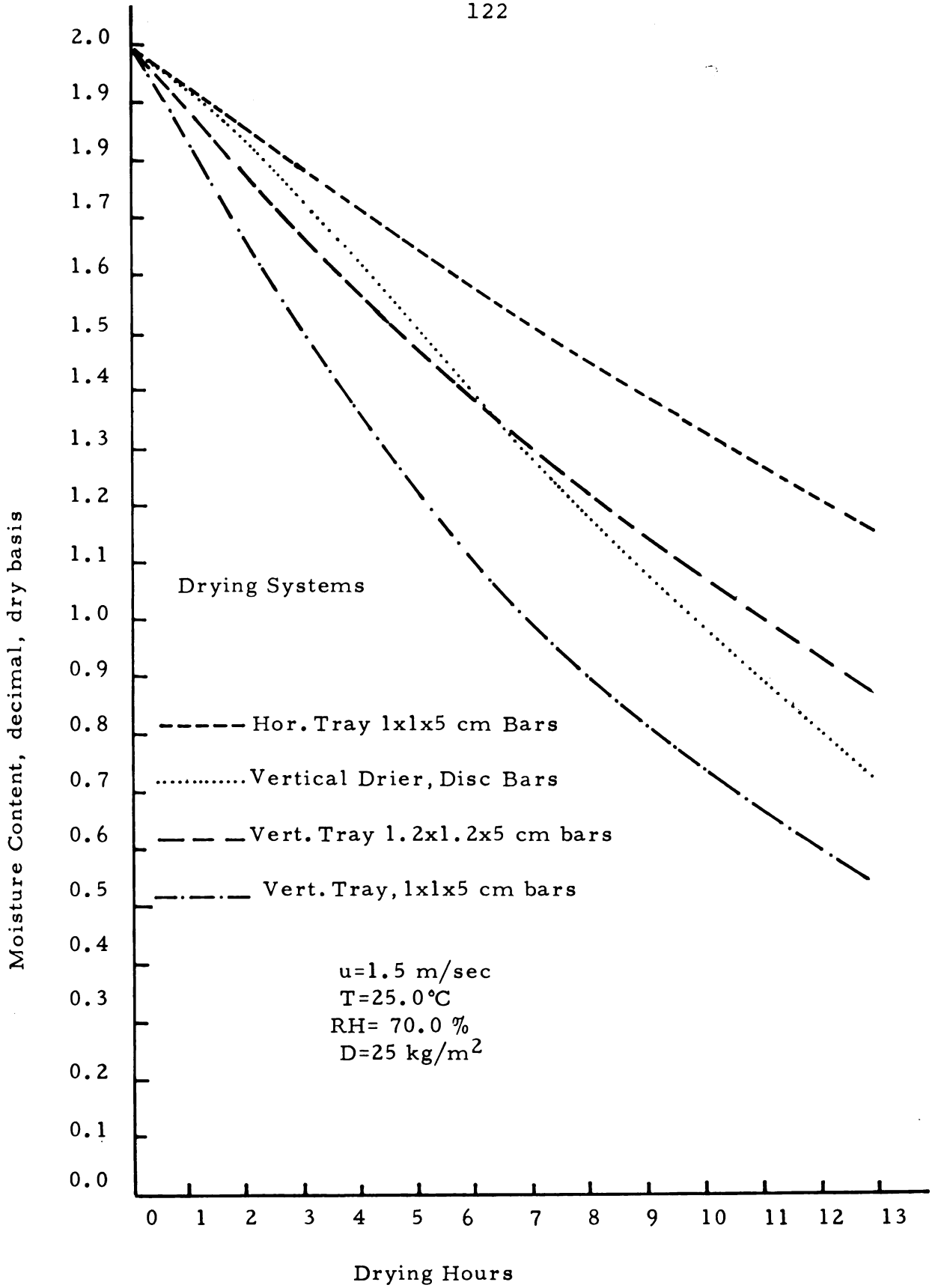

Figure 33. Comparison of Performances of Drying Systems

higher heat and mass transfer (section 2.7.3). These implications are more important than the disadvantage of the drier height (2 meters). In fact, the product dried slower at the top of the drier because of the diminishing effect of the moisture released in the bottom and central parts. The released water vapor moves upwards because of the buoyancy forces caused by concentration differences (section 2.7.3). The phenomenon of slower drying in the top was observed by the color gradient established along the height of the drier in two experiments when the weather conditions were poor.

The wings do not accelerate drying as was expected because (a) when the wind is blowing along the plane of the drier, the wings obstruct its movement, and (b) the beneficial effect of a percentage increment in wind velocity through the layer, when its direction is perpendicular to the drier, is not very large (as is shown in section 6.6).

Figure 33 shows a more complete comparison of the vertical drier with wings loaded with disc bars and other drying systems. In summary, the vertical tray with neat rectangular bars dimension 1x1x5 cm is much more efficient than the vertical drier. In turn, the vertical drier is slightly superior to the tray with bars of dimensions 1.2x1.2x5.0 cm.

6.3 Thick Layer Drying Equation

Having tested the goodness of the drying model in its finite form and the accurate results obtained using average daily weather conditions,

it was desirable to integrate equation (5.1) to be applicable for any process time. Equation (5.1) can be written in the form

$$\frac{dM}{M^2 + \frac{f_1}{f_2} M + \frac{f_0}{f_2}} = f_2 f_3 (a_4 - a_5 D)\ dt \qquad (6.4)$$

where

$$f_0 = \left[a_0 + a_1 u + a_2 (e_s - e_a) \right] M_{eq}$$

$$f_1 = - \left[a_0 + a_1 u + a_3 (e_s - e_a) - a_2 (e_s - e_a) M_{eq} \right]$$

$$f_2 = - a_2 (e_s - e_a)$$

$$f_3 = a_6 + a_7 P + a_8 S$$

or in the form

$$\frac{dM}{(M + g_0)(M + g_1)} = (g_2 + g_3 D)\ dt \qquad (6.5)$$

where

$$g_0 = \frac{f_1}{f_2} - g_1$$

$$g_1 = 0.5 \left[\frac{f_1}{f_2} + \left(\frac{f_1^2}{f_2^2} - 4 \frac{f_0}{f_2} \right)^{0.5} \right]$$

$$g_2 = a_4 f_2 f_3$$

$$g_3 = a_6 f_2 f_3$$

which can be integrated by partial fractions

$$M = \frac{g_0 (M_0 + g_1) - g_1 (M_0 + g_0) \exp \left[(g_1 - g_0)(g_2 + g_3 D)\, t \right]}{-(M_0 + g_1) + (M_0 + g_0) \exp \left[(g_1 - g_0)(g_2 + g_3 D)\, t \right]} \qquad (6.6)$$

or solving for the density D

$$D = \frac{\ln\left[\frac{M+g_0}{M+g_1} \cdot \frac{M_0+g_1}{M_0+g_0}\right]}{(g_1 g_3 - g_0 g_3)\, t} - \frac{g_2}{g_3} \qquad (6.7)$$

where all symbols are the same as above.

Expression (6.6) is an empirical thick layer drying equation for cassava, valid for (a) the total range of moisture content, (b) fixed or variable ambient conditions, (c) all drying systems, (d) variable dimensions of the rectangular bars, and (e) variable layer densities.

The accuracy of equation (6.6) with respect to the finite form (5.1) depends on the discretization or truncation errors (Carnahan et al., 1969) created in the approximations given by equations (5.7) and (5.8). Although an analytical expression for the truncation errors could be calculated based on the Taylor expansions of both expressions, a direct comparison using equations (5.1) and (6.7) is preferred in this practical study. The comparisons are given in section 6.4.

A preliminary test of equation (6.6) was made by applying it to a deep bed drying experiment consisting of a plexiglass cylinder of about 15 cm of diameter and 25 cm in height, filled with cassava slices of about 0.5 cm thickness subjected to forced air at 23.8 °C, 65 percent relative humidity and approximately 10 m/sec under controlled conditions.

Experimental average moisture content values were used to calculate the drying proportionality $\bar{K}$ values (equation 4.1). The relevant coefficients of the model (5.1) were estimated in the same way as described for the natural drying analysis in section 5.3.1. Non-estimated parameters were fixed to values of one and zero in order to use equation (6.6) unchanged to predict the bed average moisture content values (Figure 34). The good agreement between experimental and predicted values tests, once more, the goodness of the model, but the simple equation is not adequate to predict general performance of deep bed drying. The residuals (Figure 34) are all of the same sign. This is explained by the cummulative type of errors (Beck, 1972) found in the residuals of the $\bar{K}$ values. In effect, the sign of these errors changed only in about 10 hours of the drying process (Figure 34). Other discussion relevant to the practical value of equation (6.6) follows.

Equation (2.7) with proportionallity "constant" given by equation (2.8) is a particular case of equation (6.6) when (a) it is applied to a thin layer, (b) the humidity of the air does not effect the drying process (only approximatelly at high air temperatures), (c) air velocity does not affect drying (only true when convective transfer coefficient is infinite).

Under these conditions equation (5.1) takes the form

$$\frac{dM}{dt} = a_3 e_s (M - M_{eq}) \qquad (6.8)$$

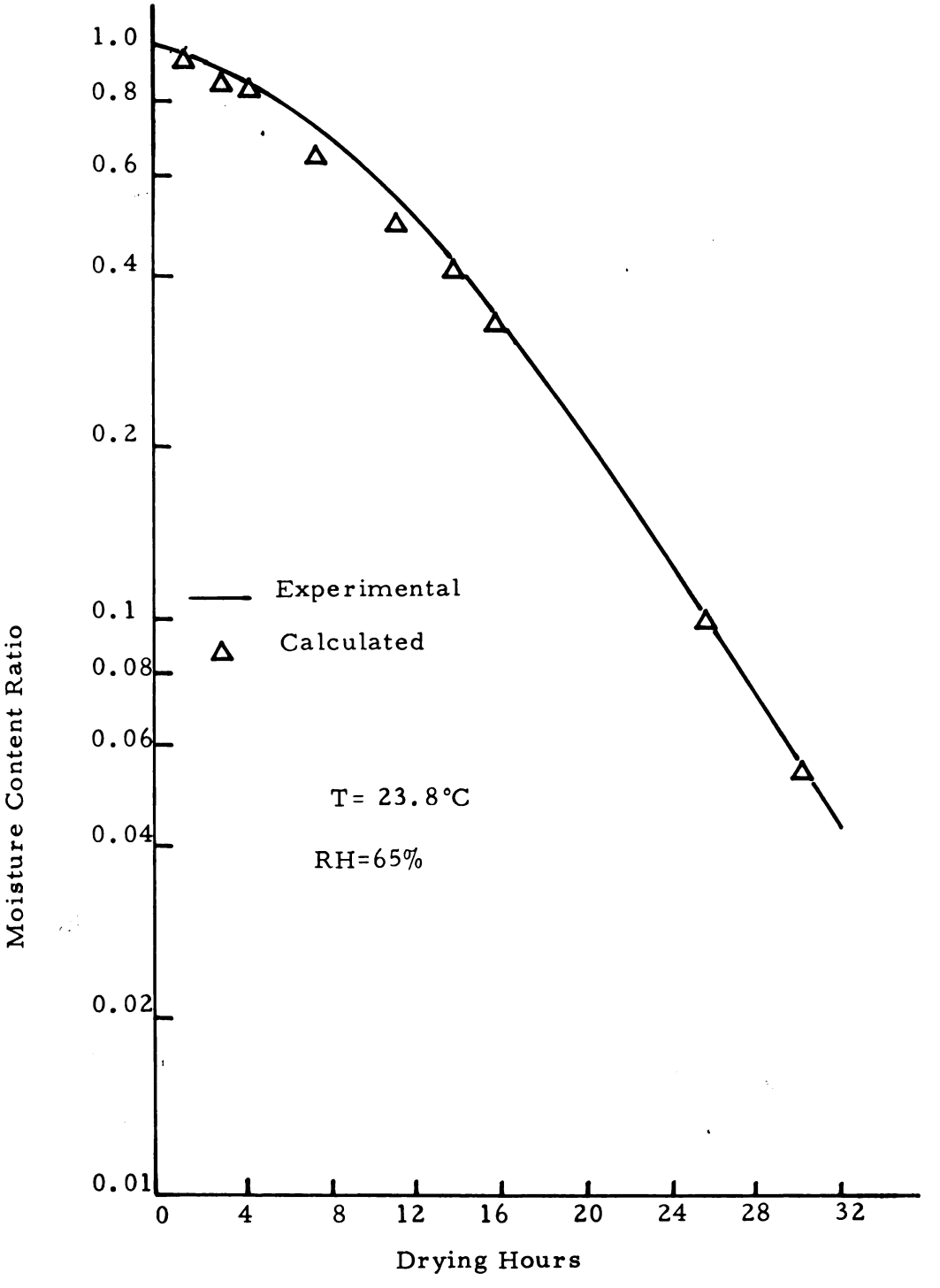

Figure 34. Cassava Deep Bed Drier

where e_s, the saturation water vapor pressure, is given by the Clausius-Clapeyron equation (Lay, 1963).

$$e_s = d_1' \exp\left(\frac{d_2}{T_{abs}}\right) \tag{6.9}$$

No functional relationship for the changes in the diffusion coefficient and shrinkage of the cassava bars were used to derive equation (6.6). Diffusion coefficients decrease with moisture content as the dimensions of the bars do. Equations (2.3) and (2.5) suggest that the two effects are dampered. The practical results obtained justify assuming constant diffusion coefficients and no shrinkege.

6.4 Maximum Density Allowable

This section is devoted to (a) developing simple graphs which provide the information needed to select the maximum density which can be dried without quality deterioration as a function of the drying conditions of the first day of drying, (b) studying the influence of the independent variables on natural drying, and (c) comparing the drying systems from a practical point of view.

The quality criteria established by deterioration observations (section 4.7) were introduced in the model by fixing the initial and final moisture content values. Initial moisture content of cassava was assumed to be 66.67 percent, w.b. (A sample mean of 66.10

percent, w.b. and a standard deviation = 1.6 percent were calculated from 126 observations). The final moisture content was fixed to 50.00 percent, w.b. for the untread cassava, and 54.00 for cassava dipped in alcohol solution. Equation (6.7) was solved for a wide range of the independent variables. A FORTRAN subroutine (CRITD) was written for this purpose. A computer main program controlled the calculations. A listing of the subroutine, main program and a example of the output are included in Appendices A9, A10, and A11. Results for the vertical drier with disc bars and an average wind velocity of 1.5m/sec are summarized in Figure 35 for different effective drying hours during one day.

The effective drying hours depend on the geographical location and the season of the year. Figure 36b was developed for different combinations of air temperature, humidity and velocity. Eleven effective drying hours were assumed to be a reasonable drying time for the tropics. The x-axis of Figure 36b is the saturation water vapor pressure deficit which is obtained from the average temperature and relative humidity (Figure 36a). Equal values of saturation water vapor pressure dificit can be obtained from different combinations of temperature and relative humidity and consequently, for different values of equilibrium moisture content. This originates a maximum error of 3 kg/m^2 from the reading of Figure 36b (The maximum differences due to differences of the equations (5.3),(5.6)

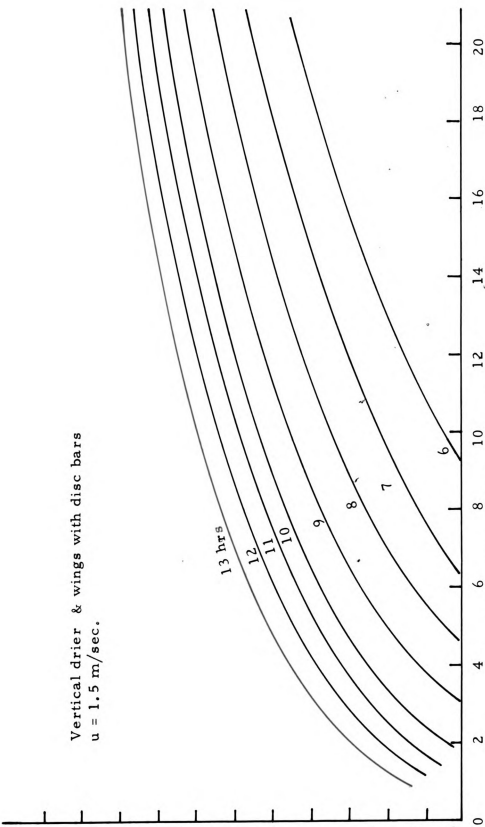

Figure 35. Maximum Density Allowed. Drying Hours

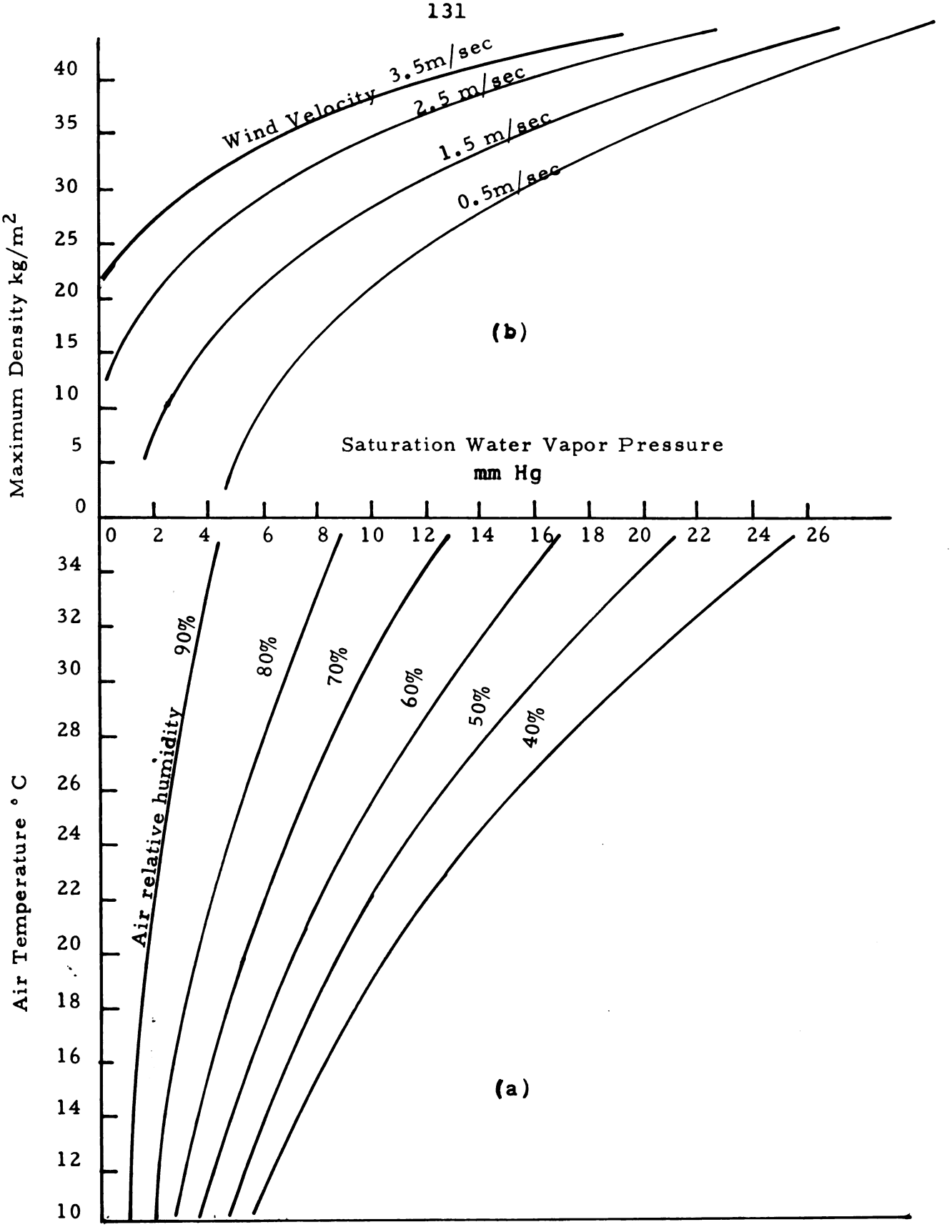

Figure 36. Maximum Density Allowed. Weather Conditions

was 1 kg/m^2 in the same range of the independent variables.

Results of the maximum allowable density were used to investigata the order of magnitude of the truncation errors due to the approximations implied by equations (5.7) and (5.8). Nine comparisons between fixed density values using equation (6.2) and calculated densities from equation (6.7) , for the same independent variables, gave an average error of only 0.2 percent. Truncation errors were therefore, negligeble.

The same computer program was used to compute the total number of hours necessary to dry the product as to 13 percent, w.b., or 1.2 times the equilibrium moisture content (in case value was higher than the specified 13 percent value). The results obtained and the practical observation made during the study indicate that the total drying process, for maximum density designed layers, occurs approximately during three or four days.

Curves of the maximum allowable density also permits practical comparisons to be made of the drying systems. Figure 37 shows the performances of 6 different drying systems. Wind velocity was assumed 1.5 m/sec. The following conclusions are drawn:

1. The vertical trays allow drying of at least 15 kg/m^2 more cassava bars that the horizontal trays.
2. The dipping of the product in the alcohol solution increases the allowable density from 5 to 10 kg/m^2 .

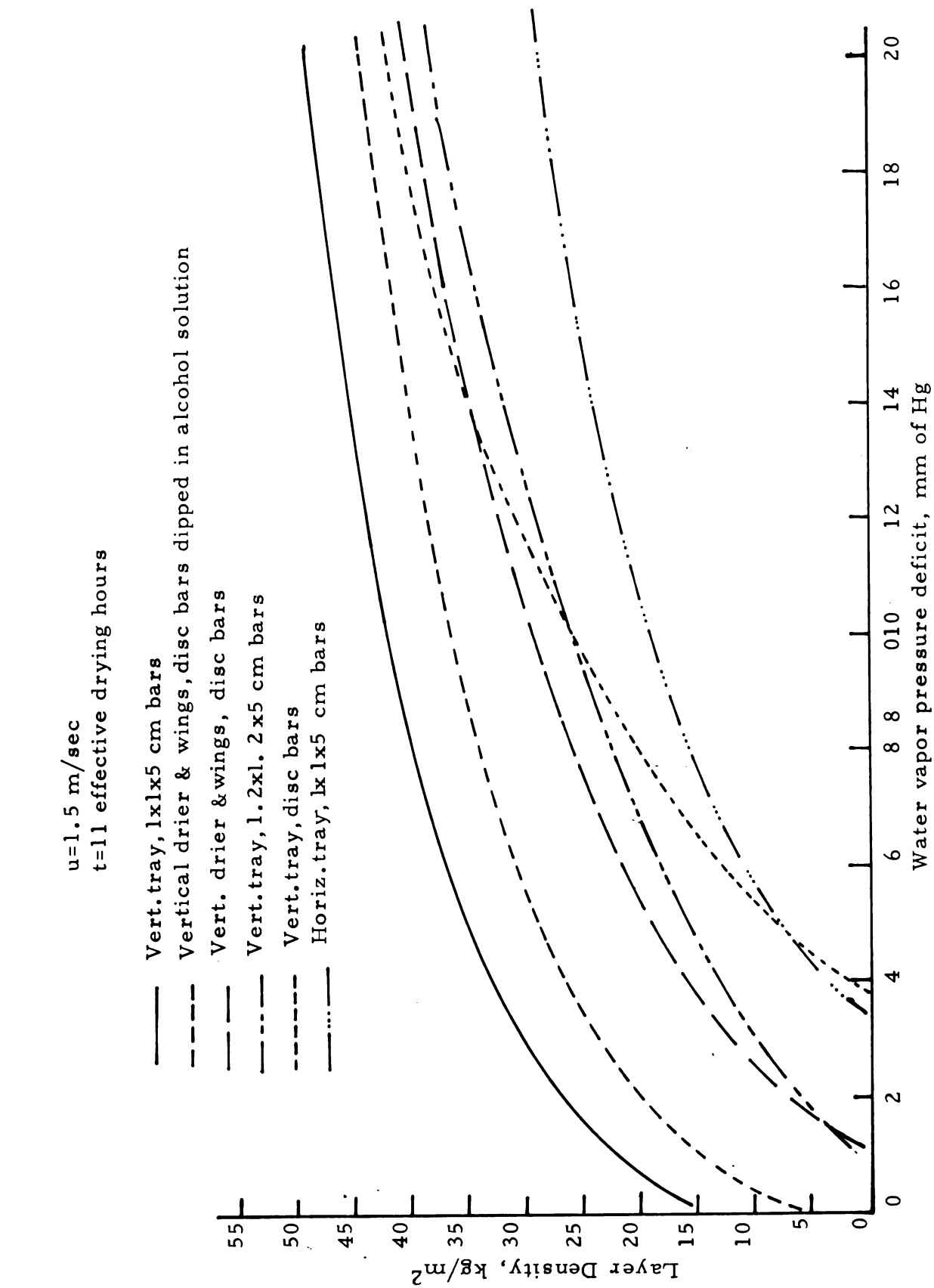

Figure 37. Maximum Density Allowed. Drying Systems.

3. the vertical drier allows more drying than the vertical trays, the amount depending on the weather conditions.
4. the disc bar performances are inferior to the 1x1x5 cm bars but approximately the same to the 1.2x1.2x5.0 cm bars.

The above points on maximum allowable density assume that the average weather conditions are known or can be predicted. Since weather prediction at present is not practiced in the developing countries, safer densities should be used. The problem is a subject of a simulation study based on risk functions and benefit-cost relationships.

6.5 Limitations of Natural Drying

Figure 36b shows the range of environmental conditions in which it is not feasible to dry cassava without deterioration for a fixed velocity. Similar curves can be make for other values of velocity. The product might or might not reach a moisture content low enough for long storage, after the recommended three days, because of hygroscopic relationships (Figure 22). Solar collectors seems to be very adequate to obtain the supplemental heat needed.

6.6 Sensitivity Analysis Based on Maximum Densities

Sensitivity analysis has in engineering equivalent importance to that that of the elasticity in economics. In fact, the mathematical relationships are the same but the results usually expressed in different manners.

The sensitivity analysis applied to the maximum density allowable

to dry without deterioration is used in this section to study the importance of all the independent variables in the process of drying of cassava naturally. The analysis provides also adequate answers to the very practical questions (a) under a typical weather condition what would be recommended to increase the maximum density, or (b) what would be the relative degree of improvement under several wether conditions.

Sensitivity coefficients X_i of a function η with respect to the variable x_i are defined as the first derivates of the function with respect to x_i (Beck, 1972).

$$X_i = \frac{\partial \eta}{\partial x_i} \tag{6.10}$$

The coefficients measure the change in the function caused by a change of the independent variable. In order to compare the sensitivity coefficients of one function with respect to several independent variables they are expressed in a normalized or percentage form of the independent variable :

$$X_i = \frac{\dfrac{\partial \eta}{\partial x_i}}{\dfrac{x_i}{}} = x_i \frac{\partial \eta}{\partial x_i} \tag{6.11}$$

A FORTRAN program was written to calculate the sensitivity coefficients of D_{max} with respect to all independent variables, and for each of the drying systems. The coefficients are :

$$X_L = L\frac{\partial D_{max}}{\partial L}\,; X_W = W\frac{\partial D_{max}}{\partial W}\,, \quad X_{T,RH} = T\frac{\partial D_{max}}{\partial T}\,, X_u = u\frac{\partial D_{max}}{\partial u} \tag{6.12}$$

Finite approximations of the derivatives were preferred to the analytical expression. The geometric properties of thee rectangular bars were written in a subroutine (DIMEQ) to facilitated the derivative calculations (See Appendix A13) . Some practical considerations enter in calculating the sensitivity coefficient with respect to the air temperature,Changes in this variable asually result from modifying the solar absorptance of the surfaces surrounding the drying system. In this process the air temperature increases at constant absolute humidity, i.e., the temperature increases and the relative humidity decreases simultaneously. The calculations of the sensitivity coefficients were made assuming this kind of change with the aid of the psychrometric model written in the VPDIF subroutine.

Evaluation of the sensitivity coefficients were made at different and representative values of the indepandent variables. The computer main program listing, and a result example are included in the Appendices A12 and A14.

Results of the sensitivity analysis are summarized in Figures 38, 39, and 40. Figure 38 compares the sensitivity coefficients of four typical combinations of temperatures and relative humidities for four values of the wind velocity. The chosen "pivot" drying system is a

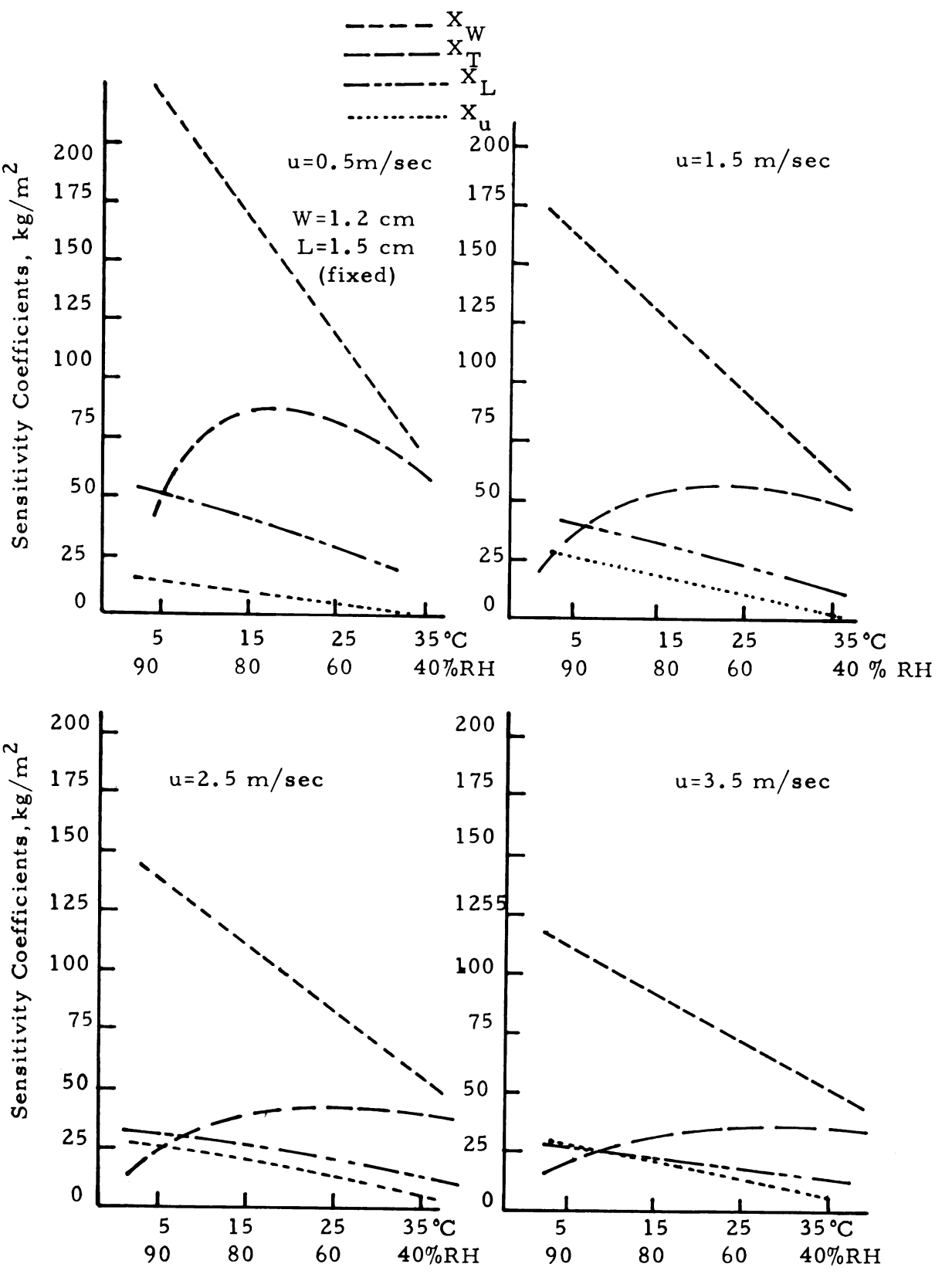

Figure 38. Sensitivity Analysis, Typical Weather.

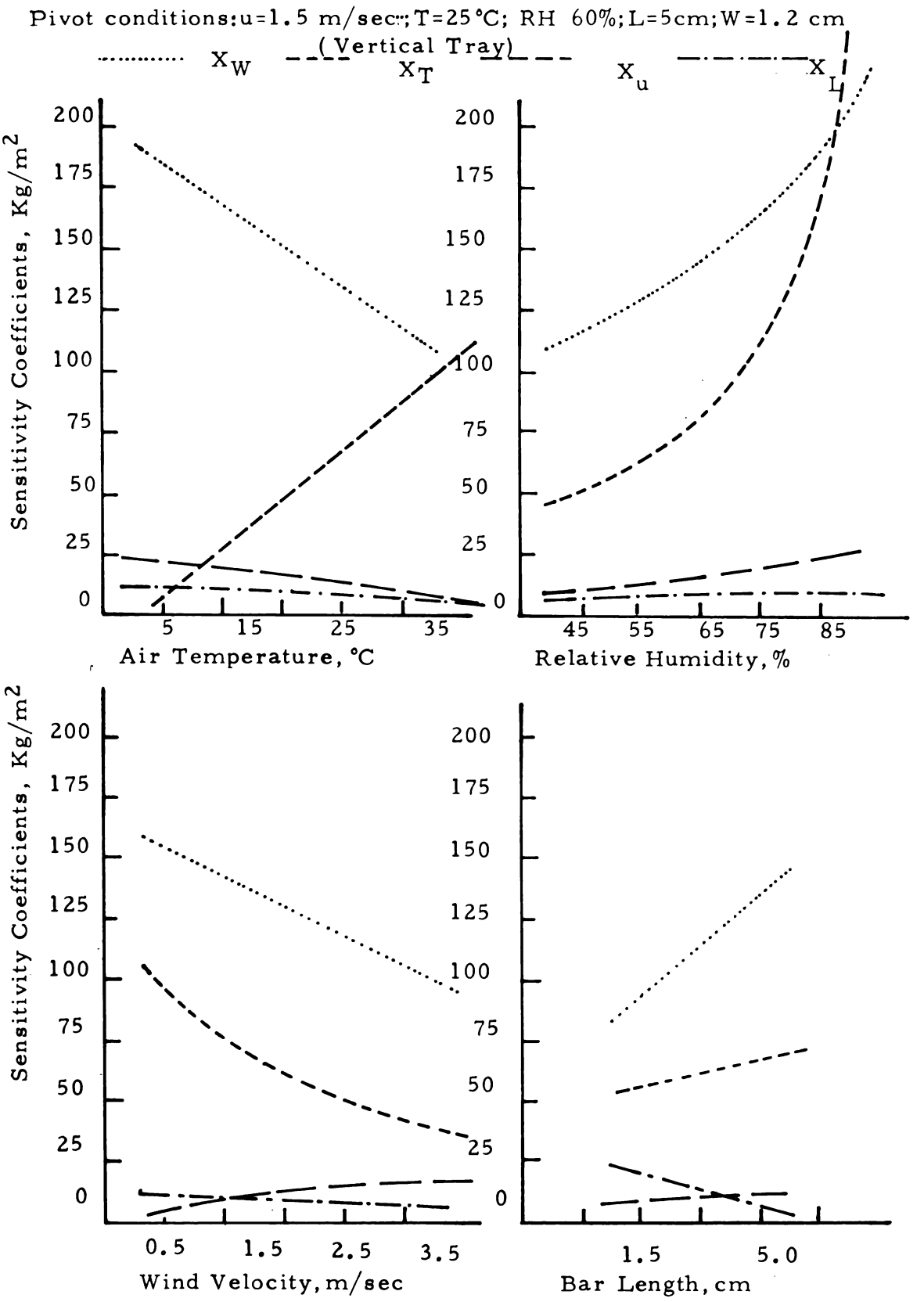

Figure 39. Sensitivity Analysis. Independent Variables

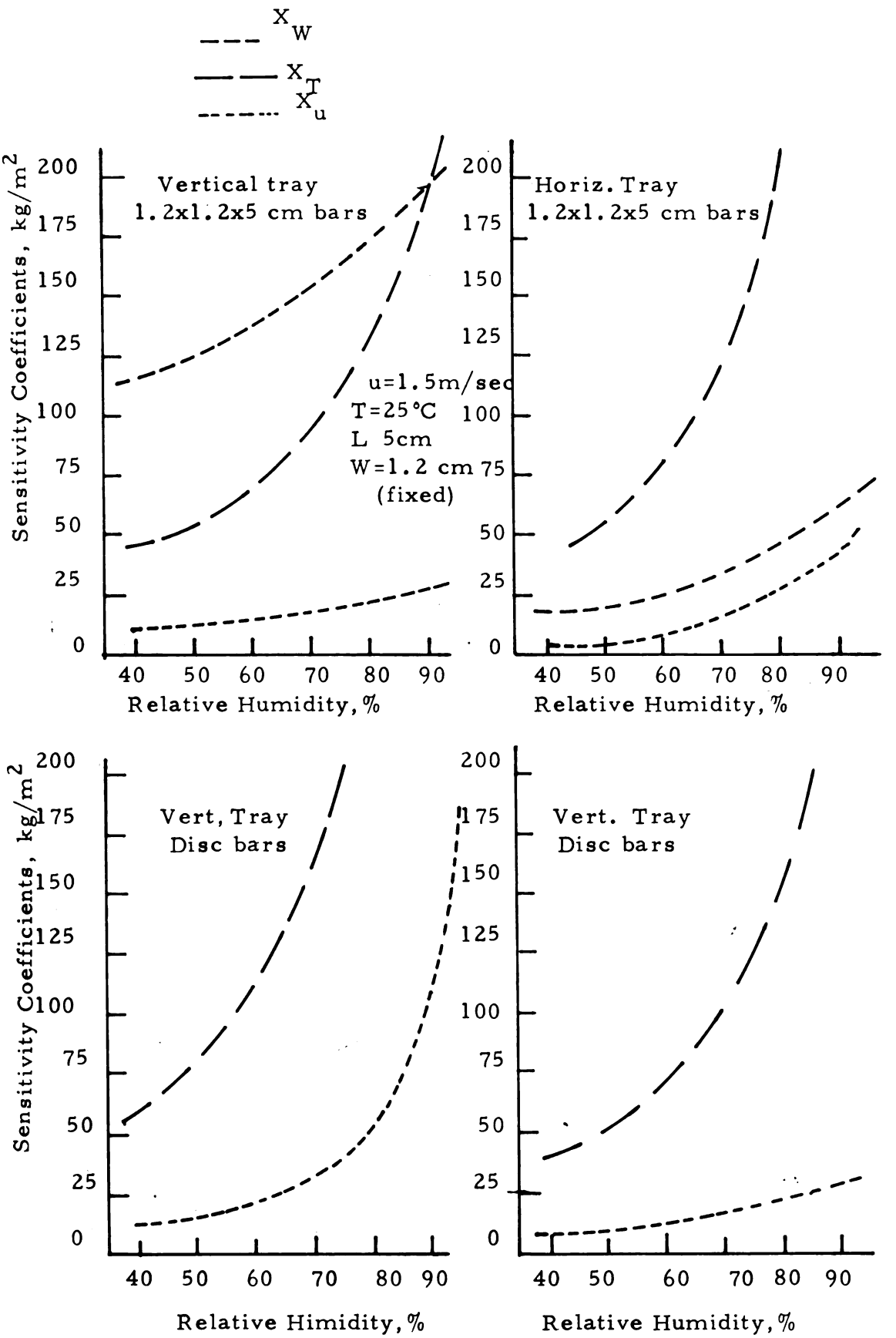

Figure 40. Sensitivity Analysis. Drying Systems.

vertical tray with rectangular bars 1.2x1.2x5.0 cm. air temperature of 25 °C and relative humidity of 60 percent. The sensitivity curves show that the order of effectiveness of the improvements is: (a) reduction of the bar section, heating of the air, reduction of the bar length, and increment of the wind velocity.

It might appear surprising that the least effective form of increasing the maximum permissible density is achieved by increasing the wind velocity, but the result is understood by interpreting change of D_{max} caused by the change of the wind velocity in percentage form, as the coefficient was calculated. Consider, for example, air at 30°C, 65 percent relative humidity, and 0.5m/sec. This gives a $(e_s - e_a)$ value of 11 mm of Hg. The D_{max} obtained is 30 kg/m^2. The same increment could be obtained by heating the air 2 °C . The percentage increment of the air temperature es 5 percent, while the percentage of the wind velocity is 200 percent.

Figure 39 compares the sensitivity coefficients calculated as function of the different values for each of the four independent variables. The pivot drying condition is a vertical tray with 1.2x1.2x5.0 cm bars subjected to air at 25 °C, 60 percent relative humidity and 1.5 m/sec of wind velocity. It is clearly shown from this figure that the first attempts to increase the efficiency of the drying system should be directed to reduce the bar section and second, to heat the air with an appropriate surrounding floor. The conditions most

susceptible to improvements are those of high humidities. This finding can be generalized in the sense that for a given system higher sensitivity coefficients indicate low performances due to the asymtotic form of the maximum density functions (see Figure 35, for example).

Figure 40 compares the performances of four drying systems based on the sensitivity curves. Curves (a) and (b) show that for a vertical tray, reduction of the bars section is the most effective improvement . For horizontal tray, however, heating of the air is the best choice. Curves (c) and (d) show that the performances of the vertical tray and the vertical drier are similar.

VII COST ANALYSIS

Cost analysis of cutting and natural drying gives the relative economic efficiency for the different systems. This subject is very important since (a) the most efficient methods are not being utilized at present and the drying systems are basically different with respect to the capital and labor inputs, (b) the selection of a given drying system will be determined by the availability of the resources of the entrepreneur.

This study, although not designed to perform cost comparisons of commercial types of operations, provides the preliminary information needed to estimate and to discriminate, with respect to the inputs, the main costs involved in the processes of cutting and natural drying. Mathematical simulation is again of paramount importance in cost estimation since average weather conditions will determine the maximum layer densities -- minimum cost -- for each of the methods of layer drying . Natural energy to dry the product does not involve any cost.

Three types of natural drying systems are analyzed : (a) drying on concrete floors, (b) drying on elevated and perforated trays and (c) drying in vertical driers.

The following are given as facts and assumptions in order to

provide meaninful comparisons between the systems:

1. the cassava particles are produced by the disc cutter.
2. drying rates for commercial drying operations are the same as those of the individual experimental models if (a) stirring of the product is performed continuosly by one man on concrete floors, (b) the horizontal trays or vertical drier are separated by a distance equal to their lengths.
3. no risk functions are considered . This implies the use of a common safety factor in selecting the maximum density recommended by the simulated results (section 6.4).
4. the vertical type of drier allows 15 kg/m^2 more drying than the horizontal elevated trays and 25 kg/m^2 more than the system of drying the product on the floor. This assumption is a conservative estimate for the vertical drier and is based on simulated results of maximum densities permissible for different weather conditions (section 6.4).
5. cost of the driers per unit area of the drier do not depend on the drier sizes.
6. total drying time for each operation is of three days (section 6.4) . Costs of further drying (if it is needed) to obtain safe moisture content values for long term storage (section 6.5), are not considered.
7. five hundred kilograms of fresh cassava are loaded on Mondays,

Tuesdays, Thursdays, and Fridays during 48 weeks of the year. This gives a total of ninety- six tons to be processed per year, the production of a farm of about 5 ha. The drying capacity of the system should be 1500 kg/week.

8. the vertical drier includes the roof cost.
9. rent of land for drying is not considered because (a) there is no experience to estimate the real area needed, and (b) these costs are known to be small compared with the drier costs for the same area.
10. two densities, 5 and 15 kg/m^2, are fixed for the concrete drying system. This gives (assumption 4) 20 and 30 kg/m^2 for the densities of the horizontal trays, and 30 and 40 kg/m^2 for the vertical drier. The low densities (for all systems) indicate poor drying conditions due to the weather. The high densities indicate good weather conditions.
11. costs are based on current material and labor prices in the Cauca Valley, Colombia (one dollar equal to 23.80 pesos, 1973 exchange rate). Figures are given in dollars.
12. the required labor for drying is assumed for each system in Tables 15 and 16. Daily wage is $1.00/day.
13. depreciation costs are different for each drying system. Actual values are given in Tables 15 and 16. Interest charge is 12 percent per year.

7.1 Cutting Data

Cutting capacity (two men working)	240 kg/hr
$\text{Labor} = \frac{96{,}000 \text{ kg/year}}{120 \text{ kg/man-hou.}} \times \frac{1}{8} \times \frac{\text{man-days}}{\text{man-hours}}$	= 100 man-days/year
machine utilization[1]	2.08 hours/day
probable life of the disc cutter	10 years
cost of cutter	US $ 150.00
annual maintenance cost (6%)	$ 9.00 year

7.2 Drying Data

7.2.1 Concrete Floors

concrete floor (1:2:3), 10 cm thick	$ 1.50/m^2
probable life	25 years
labor in handling and stirring	Tables 15 and 16

7.2.2 Horizontal Trays

tray cost	$ 3.00/m^2
probable life	7 years
maintenance 15%	$ 0.45/m^2-year
tray support cost	$ 1.00/m^2-year

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[1] This is a good practical estimation since the cut product should be ready, for drying, early in the morning.

probable life	10 years
maintenance 10%	$ 0.10/m^2-year
labor in handling	Tables 15 and 16

7.2.3 Vertical Drier

drier cost	$ 20.00/m^2
probable life	10 years
maintenance (7%)	$ 1.40/m^2-year

7.3 Cutting Costs

Cutting costs are summarized in Table 14. Calculation of the costs per unit dry weight is based on a ratio between fresh and dried weights equal to 2.5.

Table 14. Cutting Costs

Item	Costs	Percentage
Depreciation = $150/10 years	$15.0	11.3
Annual interest charge=75x.12	9.0	6.6
Maintenance = 150x.06	9.0	6.6
Labor= 100 man-days 00/day	100.0	75.1
Cost per year for 96 tons	133.0	100.0
Cost per year per freshton	1.4	
Cost per year per dried ton	3.5	

7.4 Drying Costs

Tables 15 and 16 present the distribution of the drying costs for the three systems and for the two, weather depending, densities.

7.5 Total Processing Costs

The total processing costs of cutting and drying are presented in Table 17 for the high and low densities, and for fresh and dry weight basis.

The following conclusions can be drawn from this "case study":

1. drying and cutting costs are approximately the same for the three systems and equal to $4.00 per fresh ton or $10.00 per dry ton. This cost represents about 12.5 percent of the present c.i.f. (cost plus insurance and freight charges) of dried cassava in the European Economic Community.
2. labor costs constitude about 90 percent of the drying

Table 15 Drying Costs for Low Densities

Item	Concrete (300 m^2)	Horiz. Tray (75 m^2)	Vert. Tray (50 m^2)
Cost of drier	$ 450.00	$ 225.00	$1000.00
Cost of supports	-	$ 75.00	-
Labor (man-days)	276	150	70
Cost for 96 ton/year	$year %	year %	$/year %

Table 15 Drying Costs for Low Densities (Continued)

Item	Concrete (300 m^2)		Horiz. Tray (75 m^2		Vert. Tray (50 m^2)	
Costs for 96 ton/year	$year	%	$/year	%	$/year	%
Depreciation of drier= new cost/prob. life	18.0	5.6	32.1	12.9	100.0	33.3
Depreciation of supports	-	-	7.5	3.0	-	-
Annual interest charge	27.0	8,4	18.0	7.2	60.0	20.0
Maintenance of drier	-	-	33.8	13.6	70.0	23.3
Maintenance of supports	-	-	7.5	3.0	-	-
Labor	276.0	86.0	150.0	60.0	70.0	23.4
Total	321.0	100.0	248.9	100.0	300.0	100.0
drying cost per fresh ton per year	3.4		2.6		3.1	
drying cost per dry ton per year	8.5		6.5		7.8	

Table 16. Drying Costs for High Densities

Item	Concrete (100 m^2)	Horiz. Tray (50 m^2)	Vert. Tray (37.5 m^2)
Cost of drier	$ 150.0	$ 150.00	$ 750.0
Cost of Tray supports	-	$ 50.00	-
Labor (man-days)	193	112	56

Table 16 (Continued) Drying Cost for High Densities

Cost for 96 ton/year	$/year	%	$/year	%	$/year	%
Depreciation of driers = new cost/prob. life	6.0	2.9	21.4	11.9	75.0	32.7
Depreciation of supports	-	-	7.1	3.9	-	-
Annual interest charge	9.0	4.3	12.0	6.7	45.0	19.7
Maintenance of drier	-	-	22.5	12.5	53.0	23.2
Maintenance of supports	-	-	5.0	2.8	-	-
Labor	193.0	92.0	112.0	62.2	56.0	24.4
Total	208.0	100.0	180.0	100.0	229.0	100.0
drying cost per fresh ton per year	2.2		1.9		2.4	
drying cost per dry ton per year	5.4		4.7		6.0	

Table 17 Total Processing Cost

Cost	Concrete		Horiz. Tray		Vert. Tray	
	Density					
	Low $	High $	Low $	High $	Low $	High $
cutting cost/fresh ton-yr	1.4	1.4	1.4	1.4	1.4	1.4
drying cost/fresh ton-yr	3.4	2.2	2.6	1.9	3.1	2.4
processing cost/f. ton-yr	4.8	3.6	4.0	3.3	4.5	3.8
cutting cost/dry ton-yr	3.5	3.5	3.5	3.5	3.5	3.5
drying cost/dry ton-yr	8.5	5.4	6.5	4.7	7.8	6.0
processing cost/d.ton-yr	12.0	8.9	10.0	8.2	11.3	9.5

costs on concrete floors, 61 percent of tray drying costs and 24 percent of the vertical drying system costs.

3. unfavorable weather conditions, indicated by the low and high densities, increased drying costs by about 40 percent in comparison to the costs incurred under favorable weather conditions.
4. cutting costs are approximately 35 percent of the total processing costs.

The acepted facts and assumptions might limit the real value of these figures because of the possible errors. When more realistic experimental data on commercial operations become available, more reliable cost figures will be obtained using the same framework of analysis.

VIII SUMMARY AND CONCLUSIONS

Traditional forms of drying cassava chips on concrete floors or wooden trays can be improved substantially without incresing the costs but making the operations less risky and more feasible, practical and attractive.

Vertical layers of rectangular cassava bars, produced by a modified conventional disc slicing machine, allow drying without deterioration of at least 20 kg/m^2 more than the amount currentl y dried safely by traditional methods. The vertical layers can be covered by a roof to protect the product from the rain. They can be left outside overnight to continue the drying process. The dehydration efficiency is not diminished by the shade from the solar radiation. Drying of the product in horizontal, elevated, wire trays is also a more efficient method than the traditional forms but less efficient than the vertical drier system.

Regardeless of the form or position of the product, the energy required for the evaporation is taken from the air enthalpy. The air circulates more easier in vertical layers of cassava with adequate geometric forms than in horizontal layers. Also higher air turbulences are created in vertical layers than horizontal layers. The

turbulences are created by the wind velocity and by buoyancy forces caused by the evaporation. The turbulences induce higher rates of heat and mass transfer.

It was possible to model the different drying systems mathematical with a simple equation which predicted all the extensive and varied experimental data accurately. The equation, empirical in nature, includes all the variables of importance in natural drying of thick layers of cassava. One of the most widely used empirical thin layer equations was showed to be a particular case of the proposed equation.

The model was used (a) for recommending maximum allowable layer densities to safely dry the product as function of the drying system, weather conditions and the effective drying hours of the first processing day, (b) for recommending the most appropriate form to improve the drying efficiency of a given natural drying system as function of the independent variables. Results indicate that the primary efforts should be directed to produce a neat, uniform and firm rectangular bar (or ideally a cube with a square section of 8 mm of size). Secondary efforts should be devoted to improving the solar absorptance of extensive area around the vertical drier, and (c) for estimating and comparing costs involved in three drying systems.

IX RECOMMENDATIONS FOR FUTURE RESEARCH

Results of this study suggest that new natural drying systems of cassava can be implemented for commercial operations. The proposed systems should increase the cassava drying industry by: (a) improving the quality of the end product, (b) making the process more economical, less risky and, in general, more attractive, and (c) providing different, low-cost, drying alternatives for different types of entrepreneur. Research is recommended to implement commercially the proposed drying systems.

The disc cutter assembly can be improved to produce firmer, smaller and more uniform rectangular bars. In order to obtain these desirable physical properties, the movement of the root, when being cut, should be eliminated, and the disc modified to avoid the bending stresses in the bars when they are cut and released by the disc. Research is also suggested to design other mechanisms for producing the desirable geometrical properties at low cost. The feasibility of reducing the initial moisture content of the roots (by using a mechanical press) prior to drying should be investigated.

Drying performances of layers in intermediate positions between the vertical and horizontal should be investigated together with (a) the

possible reduction in costs of the drier structure, (b) the practicality of loading and unloading the drier, (c) the protection of the product with shade, and (d) the type and availability of construction materials.

Implementation of solar collectors to produce the supplemental heat needed to reduce the cassava moisture content to a safe long storage value would be the logical complement of the natural drying system studied. The collector might be design to complement the design of the natural drying system in order to reduce costs.

The applicability of the new natural drying technology to other products which are presently dried using the same conventional methods should be investigated. The mathematical model can be generalized to products in which solar absorption is significant. The general drying equation would be adequate to perform sensitivity analysis which, in turn, would indicate how to improve the drying methods.

The proposed drying equation seems to be applicable to give a practical solution to the diffusion equation with convective boundary conditions. The equation might result in a general thin drying equation. Also, simplified deep bed calculations, using the density function, are promising.

Hygroscopic data of any product seems to be predictible with acceptable errors by using the presented double polynominal function.

APPENDICES

APPENDIX A

APPENDIX A

COMPUTER PROGRAMS

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LEGEND OF ANOTATIONS

AVMC	Calculated moisture content using average daily weather conditions, decimal, dry basis
AVRMC	Calculated moisture content ratio using average daily weather conditions
AVWMC	Calculated moisture content using average daily weather conditions, decimal, wet basis
CM	Calculated moisture content, decimal, dry basis
CMC	Critical moisture content, decimal, dry basis
CMCD1	Initial moisture content for each hour, decimal, dry basis
CMCD	Calculated moisture content, decimal, dry basis
CMCR	Calculated moisture content ratio
CMCW	Calculated moisture content, decimal, wet basis
COULS	Counter of number of experiments for each drying system
COUNT	Counter of total measurements fo each drying system
CRITD	Subroutine to calculate the maximum layer density allowable to dry safely
CRTD	Maximum density allowable to dry safely, kg/m^2
DATE	Date of experiment
DC	Difference between calculated and experimental moisture content
DEN	Density, kg/m^2
DENPT	Fresh cassava weight per tray, kg
DIMEQ	Subroutine to calculate geometric properties of rectangular cassava bars

EA	Water vapor pressure, lb/in^2
EQ100	Equilibrium moisture content, percent, dry basis
EQEQ	Subroutine to calculate the equilibrium moisture content
EQMC	Equilibrium moisture content, decimal, dry basis
ES	Saturation water vapor pressure, lb/in^2
ESMEA	Saturation water vapor pressure deficit, lb/in^2
FE	Mean error of final moisture values calculated using average daily conditions
I	Index for hourly measurements
IP1	I + 1
ITYPE	Form of input data : 1= tray drying in 1973; 2= tray drying in 1972; 3 = vertical drying; 4=vertical drying with corrections for the RH measurements.
J	Index for trays
KEXEQ	Subroutine to calculate the drying proportionality constant
KEXP	Experimental drying proportionality constant, hr^{-1}
LAYEQ	Subroutine to calculate discrete moisture content values
LDIM	Length of the rectangular bar, cm
N	Drying system
NCLAS	Drying system
NDAY	Day of the experimental: 1=first day; 2= second day
NMEAS	Number of experimental measurements per day
NN	Drying system
NTRAY	Number of drying tests in a drying experiment
PAR	Coefficients of the thick layer equation

POR	Porosity
RH100	Relative humidity, percent
RH	Relative humidity, decimal
RHER	Relative humidity measured with calibration errors
RSQD	Total coefficient of determination
SCTAH	Sensitivity coefficient of the maximum density with respect to heating of the air, kg/m^2
SCU	Sensitivity coefficient of the maximum density with respect to the wind velocity, kg/m^2
SCW1	Sensitivity coefficient of the maximum density with respect to the length of the bar, kg/m^2
SCW2	Sensitivity coefficient of the maximum density with respect to the thickness of the bar section, kg/m^2
SDIM	Thickness of the bar section, cm
SIGD	Rectangular bar geometric property, cm^{-2}
SE	Moisture content error for each system
TEMPC	Dry bulb temperature, °C
TOTH	Total hours needed to dry the particles as to 13 percent, wet basis, or as to 1.2 times the equilibrium moisture content, hours
TNUM	Tray or test number
TPOS	Position of the tray: 1=vertical; 2=horizontal
UMPS	Wind velocity, m/sec
UNOTS	Wind velocity, nautical miles/hour
VPDIF	Subroutine to calculate the saturation water vapor pressure deficit

W100	Weight of the cassava dry matter plus the tray weight and the tray frame weight, kg
WBLOC	Weight of auxiliary blocks for measuring l, kg
WD	Dried weight of cassava, kg
WDIM	Thickness of the bar section, cm
WDRYR	Weight of the empty vertical drier, kg
WFRAM	Weight of the vertical tray frame, kg
XMCD	Experimental moisture content, decimal, dry basis
XMCI	Initial moisture content, decimal, dry basis
XMCR	Experimental moisture content ratio
XMCW	Experimental moisture content, decimal, wet basis
XMER	Experimental moisture content determined with oven set at 75 °C
WPL	Weight of an auxiliary plywood used in the vertical drier, kg
WT	Total weight measured every hour, kg
WTRAY	Weight of the tray, kg

APPENDIX A

A1

```
C*****
C*****
C***** SUBROUTINE TO CALCULATE THE CASSAVA EQUILIBRIUM MOISTURE
C***** CONTENT AT A GIVEN DRY BULB TEMPERATURE AND RELATIVE HUMIDITY
C*****
C*****
      SUBROUTINE EQEQ(I)
      DATA A,B,C,D,E/.8415195E01,-.592946,.329233E-01,-.566854E-03
     1,.332141E-05/
      DATA P,Q,R,S,T/2.40548,-.0119525,.0221382,-.037224,.0248253/
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      TEMPK=TEMPC(I)+273.
      RU=RH(I)
      EQ1 = A+RU*(B+RU*(C+RU*(D+RU*E)))
      EQ2 = P+(Q+RU*(R+RU*(S+T*RU)))*TEMPK
      EQMC(I)=EQ1 * EXP( EQ2 ) / 100.
      RETURN
      END
```

A2

```
C*****
C*****
C***** SUBROUTINE TO CALCULATE THE EXPERIMENTAL DRYING PROPORTIONALITY
C***** CONSTANT 'K'.
C*****
C*****
      SUBROUTINE KEXEQ(I,J,KEXP)
      REAL KEXP
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      IP1=I+1
      KEXP=(2.*(XMCD(I,J)-XMCD(IP1,J)))/(XMCD(I,J)+XMCD(IP1,J)-2.*EQMC(I
     1))
      RETURN
      END
```

A3

```
C*****
C*****
C***** SUBROUTINE TO CALCULATE THE DIFFERENCE BETWEEN THE SATURATED
C***** WATER VAPOR PRESSURE AND THE ACTUAL WATER VAPOR PRESSURE AT A
C***** GIVEN DRY BULB TEMPERATURE AND RELATIVE HUMIDITY
C*****
C*****
      SUBROUTINE VPDIF( I)
      DATA PR,PA,PB,PC,PD,PE,PF,PG/.3206182232E04,-.274055258361426E05,.
     1541896076328951E02,-.451370384112655E-1,.215321191636354E-4,-.4620
     226656819982E-8,.241612720987401,.121546516706055E-2/
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      TEMPR=TEMPC(I)*1.8+32.+459.69
      ES=PR*EXP((PA+TEMPR*(PB+TEMPR*(PC+TEMPR*(PD+TEMPR*PE))))/(TEMPR*(P
     1F-PG*TEMPR)))
      PS(I)=ES
      RU=RH(I)
      EA=ES*RU
      ESMEA(I)= 51.71*(ES-EA)
      RETURN
      END
```

```
C*****
C*****
C*****  SUBROUTINE TO CALCULATE DISCRETE MOISTURE CONTENT VALUES IN
C*****  DRYING THICK LAYERS OF CASSAVA AS A FUNCTION OF THE DRYING
C*****  SYSTEM, LAYER DENSITIES, INITIAL MOISTURE CONTENT , AND WEATHER
C*****  CONDITIONS
C*****
C*****
      SUBROUTINE LAYEC(I,J,NN,CM,K,NM)
      DATA PAR1,PAR2,PAR3,PAR4/.04757,.01809,-.00231,.00752,1.53686,-.02
     12139,-1.06337,1.86295,.52454,-.0026,.01186,-.00183,.00692,2.39961,
     2-.061475,-.80926,2.66468,.21248,-.01382,.02482,-.00513,.01312,1.55
     3848,-.025258,1.0,0.0,0.0,-.00462,-.00106,-.00217,.00861,2.048,-.05
     125,1.0,0.0,0.0/
      DATA PAR5,PAR6,PAR7,PAR8,PAR9/-.02317,.053475,-.0043966,.010067,1.
     17091,-.0277,1.,0.,0.,.0178,.0144,-.006,.01278,1.7091,-.0277,1.,0.
     2,0.0,.07024,.0329918,-.00072161,.000961559,3.25358,-.140855,1.0,0.
     30,0.0,.12780,.0475165,-.00216667,.00165901,1.82662,-.0695239,1.0,0
     4.0,0.0,.00766,.041716,-.00091263,.0025695,2.6564,-.0837894,1.0,0.0
     5,0.0/
      DATA B4 /.5/
      DIMENSION T(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      DIMENSION PAR(9,9),PAR1(9),PAR2(9),PAR3(9),PAR4(9),PAR5(9),PAR6(9)
     1,PAR7(9),PAR8(9),PAR9(9)
      COMMON T,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      IF(IFLAG-3)5,6,5
    5 CONTINUE
      DO 10 L=1,9
      PAR(L,1)=PAR1(L)
      PAR(L,2)=PAR2(L)
      PAR(L,3)=PAR3(L)
      PAR(L,4)=PAR4(L)
      PAR(L,5)=PAR5(L)
      PAR(L,6)=PAR6(L)
      PAR(L,7)=PAR7(L)
      PAR(L,8)=PAR8(L)
      PAR(L,9)=PAR9(L)
   10 CONTINUE
    6 CONTINUE
      B0=PAR(1,NN)+PAR(2,NN)*UMPS(I)+PAR(3,NN)*CMCD1(NM)*ESMEA(I)/2.+PAR
     1(4,NN)*ESMEA(I)
      B1= PAR(3,NN)*ESMEA(I)/2.
      B2=(PAR(5,NN)+PAR(6,NN)*DEN(K))*(PAR(7,NN)+PAR(8,NN)*CMCD1(NM)+PAR(9,
     1NN)*SIGD(J))
      B3=CMCD1(NM)/2.-EQMC(I)
      C0=B1*B2*B4
      C1=B0*B2*B4+B1*B2*B3+1.
      C2=B0*B2*B3-CMCD1(NM)
      CM=(-C1+SQR((C1*C1-4.*C0*C2))/(2.*C0)
      CMCD1(NM)=CM
      IFLAG=3
      RETURN
      END
```

```
C*****
C*****
C*****
C*****  PROGRAM TO PREDICT NATURAL DRYING OF CASSAVA - PREDICTED RESULTS
C*****  ARE COMPARED WITH EXPERIMENTAL VALUES
C*****
C*****  THE MODEL PREDICTS IN A DISCRETE FORM HOURLY MOISTURE CONTENTS
C*****  AS A FUNCTION OF VARIABLE WEATHER CONDITIONS, DIFFERENT NATURAL
C*****  DRYING SYSTEMS AND DIFFERENT DENSITIES
C*****
C*****  NINE DRYING SYSTEMS ARE DESCRIBED BY A SIMPLE THICK LAYER
C*****  EQUATION. - THE SYSTEMS STUDIED ARE

C*****    NCLAS(1)   RECTANGULAR BARS OF VARIABLE DIMENSIONS PLACED ON
C*****               VERTICAL PERFORATED TRAYS
C*****    NCLAS(2)   RECTANGULAR BARS OF VARIABLE DIMENSIONS ON
C*****               PERFORATED HORIZONTAL TRAYS
C*****    NCLAS(3)   RECTANGULAR BARS PRODUCED BY A DISC CUTTER ON
C*****               PERFORATED VERTICAL TRAYS
C*****    NCLAS(4)   RECTANGULAR BARS PRODUCED BY A DISC CUTTER ON
C*****               PERFORATED HORIZONTAL TRAYS
C*****    NCLAS(5)   RECTANGULAR BARS PRODUCED BY A DISC CUTTER ON A
C*****               VERTICAL DRIER
C*****    NCLAS(6)   RECTANGULAR BARS PRODUCED BY A DISC CUTTER ON  A
C*****               VERTICAL DRIER MODIFIED WITH WINGS
C*****    NCLAS(7)   NON-UNIFORM LARGE CASSAVA CHIPS ON PERFORATED
C*****               HORIZONTAL TRAYS
C*****    NCLAS(8)   NON-UNIFORM SMALL CASSAVA CHIPS ON PERFORATED
C*****               HORIZONTAL TRAYS
C*****    NCLAS(9)   RECTANGULAR BARS ON THE FLOOR
C*****
C*****
C*****
C*****
      REAL LDIM(10),LL,KEXP
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      DIMENSION TNUM(10),TPOS(10),NCLAS(10),WT(10),W100(10),WBLOC(10),WF
     1RAM(10),WTRAY(10),DATE(15),CH(2,4),CMCD(20,10),XMCW(10),CMCW(10),X
     2MCR(10),CMCR(10),XMCI(10),SDIM(10),WDIM(10),AVWMC(10),AVRMC(10),AV
     3IMC(10),XMER(20),SC(6),DC(6),DCS(6),SE(6),EXPK(20,10),XAVTE(20,10)
     4,YEXP(2000),COUNT(9),COULS(9),PSE(9,6),SPSE(9,6),PSEL(9,6),SPSEL(9
     5,6),AVMCD(20,10)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      DATA CH/19.2819,.8141,0.0,1.0,19.2819,.8141,27.3229,.6880/
      NDATA=0
      NTT=0
      SSRD=0.0
      SSRW=0.0
      TDCSD=0.0
      TDCSW=0.0
      DO 62 N=1,9
      COUNT(N)=0.
      COULS(N)=0.
      DO 62 K=1,6
      SPSE(N,K)=0.0
      SPSEL(N,K)=0.0
   62 CONTINUE
   30 CONTINUE
      READ(8,80)DATE,NTRAY,NMEAS,ITYPE
      IF(ITYPE-999)59,58,59
   59 CONTINUE
      WRITE(5,120)
      WRITE(5,81)DATE,ITYPE,NTRAY,NMEAS
      GO TO (1,1,2,2),ITYPE
    2 CONTINUE
      DO 54 J =1,NTRAY
   54 READ(8,96)WDRYR,WPLYW,NCLAS(J),WD,NDAY
      GO TO 3
    1 CONTINUE
      DO 4 J=1,NTRAY
      GO TO (5,6),ITYPE
    5 READ(8,82)DENPT,SDIM(J),WDIM(J), LDIM(J),TPOS(J),TNUM(J),W100(J),W
     1TRAY(J),WBLOC(J),WFRAM(J),NCLAS(J)
      GO TO 7
    6 READ(8,83)DENPT,SDIM(J),WDIM(J),LDIM(J),TPOS(J),TNUM(J),NCLAS(J)
    7 NN=NCLAS(J)
      GO TO (8,8,9,9,9,9,9,9,8),NN
    8 SS=SDIM(J)*SDIM(J)
      WW=WDIM(J)*WDIM(J)
      LL=LDIM(J)*LDIM(J)
      SIGD(J)=1./SS+1./WW+1./LL
```

```
      POR(J)=(.420+.0166*LDIM(J)) * (1.1609-.144*SDIM(J))
    9 DEN(J)=4.*DENPT
    4 CONTINUE
    3 CONTINUE
      GO TO (22,16,45,45),ITYPE
   22 READ(8,84)(WT(J),J=1,NTRAY)
      GO TO 46
   45 READ(8,98)(WT(J),J=1,NTRAY)
   46 CONTINUE
      GO TO (25,18,18,18),ITYPE
   18 CONTINUE
      GO TO (56,57),NDAY
   56 CONTINUE
      DO 55 J=1,NTRAY
   55 DEN(J)=(WT(J)-WDRYR-WPLYW)/3.
   57 CONTINUE
      DO 26 J=1,NTRAY
      XMCD(1,J)= (WT(J)-WDRYR-WPLYW-WD)/WD
   26 CONTINUE
      GO TO 20
   25 CONTINUE
      DO 27 J=1,NTRAY
      XMCD(1,J)=(WT(J)-W100(J)-WBLOC(J) )/(W100(J)-WTRAY(J)-WFRAM(J) )
   27 CONTINUE
      GO TO 20
   16 READ(8,85)(XMER(J),J=1,NTRAY)
      DO 44 J=1,NTRAY
   44 XMCD(1,J)=(XMER(J)+1.)/.98-1.
   20 CONTINUE
      DO 23 J=1,NTRAY
      XMCI(J)=XMCD(1,J)
      CMCDI(J)=XMCD(1,J)
   23 CONTINUE
      STC=0.
      SRU=0.
      SU=0.
      DO 10 I=1,NMEAS
      IP1=I+1
      READ(8,89)TEMPC(I),RHER,UNOTS
      RH(I)=( CH(1,ITYPE) + CH(2,ITYPE)*RHER ) / 100.
      GO TO (40,41,40,40),ITYPE
   40 UMPS(I)= .5144*UNOTS
      GO TO 42
   41 UBADU=UNOTS
      UMPS(I)=UBADU*51.44/447.
   42 CONTINUE
      STC=STC+TEMPC(I)
      SRU=SRU+RH(I)
      SU = SU+ UMPS(I)
      CALL VPDIF(I)
      CALL EQEQ(I)
      GO TO (11,12,47,47),ITYPE
   11 READ(8,84)(WT(J),J=1,NTRAY)
      GO TO 13
   47 READ(8,98)(WT(J),J=1,NTRAY)
      GO TO 13
   12 READ(8,85)(XMER(J),J=1,NTRAY)
      DO 43 J=1,NTRAY
   43 XMCD(IP1,J)=(XMER(J)+1.)/.98-1.
   13 CONTINUE
      DO 10 J=1,NTRAY
      GO TO(15,24,17,17),ITYPE
   15 XMCD(IP1,J)=(WT(J)-W100(J)-WBLOC(J) ) / ( W100(J)-WTRAY(J)-WFRAM(J
     1) )
      GO TO 24
   17 XMCD(IP1,J)=(WT(J)-WDRYR-WPLYW-WD)/WD
   24 CONTINUE
      CALL KEXEQ(I,J,KEXP)
      EXPK(I,J)=KEXP
      XAVTE(I,J)=(XMCD(IP1,J)+XMCD(IP1,J))*ESMEA(I)/2.
      NN=NCLAS(J)
      CALL LAYEQ(I,J,NN,CM,J,NN)
      CMCD(IP1,J)=CM
   10 CONTINUE
      RMES = NMEAS
      II= NMEAS+1
      TEMPC(II)=STC/RMES
      RH(II)=SRU/RMES
      UMPS(II)=SU/RMES
      DO 31 J=1,NTRAY
      NTT=NTT+1
      AVMCD(1,J)=XMCD(1,J)
      CMCDI(J)=XMCD(1,J)
      AVIMC(J)=XMCD(1,J)
```

```
      NN=NCLAS(J)
      COULS(NN)=COULS(NN)+1.0
      CALL VPDIF(II)
      CALL EQEQ(II)
      DO 38 I=1,NMEAS
      IP1= I + 1
      CALL LAYEQ(II,J,NN,CA,J,NN)
      AVMCD(IP1,J)=CA
   38 CONTINUE
      GO TO (32,32,33,33),ITYPE
   32 CONTINUE
      GO TO (36,36,34,34,34,34,34,34,36),NN
   36 WRITE(5,90)TNUM(J),TPOS(J),DEN(J),NN,SDIM(J),WDIM(J),LDIM(J),POR(J
     1),SIGD(J)
      GO TO 35
   34 WRITE(5,91)TNUM(J),TPOS(J),DEN(J),NN
      GO TO 35
   33 WRITE(5,94)DEN(J),NCLAS(J)
   35 CONTINUE
      WRITE(5,93)
      XMCW(J)=XMCD(1,J)/(1.+XMCD(1,J))
      XMCR(J)=(XMCD(1,J)-EQMC(I))/(XMCI(J)-EQMC(I) )
      CMCD(1,J)=XMCD(1,J)
      CMCW(J)=XMCW(J)
      CMCR(J)=XMCR(J)
       AVWMC(J)=XMCW(J)
      AVRMC(J)=XMCR(J)
      WRITE(5,92)XMCD(1,J),CMCD(1,J),AVMCD(1,J),XMCW(J),CMCW(J),AVWMC(J)
     1,XMCR(J),CMCR(J),AVRMC(J)
      DO 48 K=1,6
   48 SC(K)=0.
      DO 31 I = 1,NMEAS
      NDATA=NDATA+1
      COUNT(NN)=COUNT(NN)+1.0
      IP1=I+1
      YEXP(NDATA)=XMCD(IP1,J)
      RH100=RH(I)*100.
      EQ100=EQMC(I)*100.
      WRITE(5,87)I,TEMPC(I),RH100,UMPS(I),ESMEA(I),EQ100
      XMCW(J)=XMCD(IP1,J)/(1.+XMCD(IP1,J))
      XMCR(J)=(XMCD(IP1,J)-EQMC(I))/(XMCI(J)-EQMC(I))
      CMCW(J)=CMCD(IP1,J)/(1.+CMCD(IP1,J))
      CMCR(J)=(CMCD(IP1,J)-EQMC(I) )/(XMCI(J)-EQMC(I))
      AVWMC(J)=AVMCD(IP1,J)/(1.+AVMCD(IP1,J))
      AVRMC(J)=(AVMCD(IP1,J)-EQMC(II))/(AVIMC(J)-EQMC(II))
      WRITE(5,92)XMCD(IP1,J),CMCD(IP1,J),AVMCD(IP1,J),XMCW(J),CMCW(J),AV
     1WMC(J),XMCR(J),CMCR(J),AVRMC(J)
      DC(1)=XMCD(IP1,J)-CMCD(IP1,J)
      DC(2)=XMCD(IP1,J)-AVMCD(IP1,J)
      DC(3)=XMCW(J)-CMCW(J)
      DC(4)=XMCW(J)-AVWMC(J)
      DC(5)=XMCR(J)-CMCR(J)
      DC(6)=XMCR(J)-AVRMC(J)
      DO 49 K = 1,6
      DCS(K)=DC(K)*DC(K)
      SPSE(NN,K)=SPSE(NN,K)+DCS(K)
   49 SC(K)=SC(K)+DCS(K)
      SSRD=SSRD+DCS(1)
      SSRW=SSRW+DCS(3)
      IF(NMEAS-I)31,52,31
   52 CONTINUE
      DO 53 K = 1,6
   53 SE(K)=SQRT(SC(K)/RMES)
      DO 64 K=1,6
   64 SPSEL(NN,K)=SPSEL(NN,K)+DCS(K)
      RHH=RH(II)*100.
      EQQ=EQMC(II)*100.
      WRITE(5,101)TEMPC(II),RHH    ,UMPS(II),ESMEA(II),EQQ
      WRITE(5,100)(DC(K),K=1,6)
      WRITE(5,99)(SE(K),K=1,6)
      TDCSD=TDCSD+DCS(1)
      TDCSW=TDCSW+DCS(3)
   31 CONTINUE
      GO TO 30
   56 RDATA=NDATA
      TSED=SQRT(SSRD/RDATA)
      TSEW=SQRT(SSRW/RDATA)
      SUMY=0.0
      DO 61 N=1,NDATA
   61 SUMY=SUMY+YEXP(N)
      AVYD=SUMY/RDATA
      AVYW=AVYD/(1.0+AVYD)
      SSTD=0.0
      SSTW=0.0
```

```
      DO 60 M = 1,NDATA
      DIFTD=AVYD-YEXP(M)
      DIFTW=AVYW-YEXP(M))/(1.+YEXP(M))
      DIFDS=DIFTD*DIFTD
      DIFWS=DIFTW*DIFTW
      SSTD=SSTD+DIFDS
      SSTW=SSTW+DIFWS
   60 CONTINUE
      RSQD=1.0-SSRD/SSTD
      RSQW=1.0-SSRW/SSTW
      RNTT=NTT
      SEFD=SQRT(TDCSD/RNTT)
      SEFW=SQRT(TDCSW/RNTT)
      DO 63 N=1,9
      DO 63 K=1,6
      PSE(N,K)=SQRT(SPSE(N,K)/COUNT(N))
   63 PSEL(N,K)=SQRT(SPSEL(N,K)/COULS(N))
      WRITE(5,120)
      WRITE(5,102)NDATA
      WRITE(5,107) AVYD,AVYW
      WRITE(5,108) SSRD,SSRW,SSTD,SSTW
      WRITE(5,104)RSQD,RSQW
      WRITE(5,103)TSED,TSEW
      WRITE(5,105)NTT
      WRITE(5,106)SEFD,SEFW
      WRITE(5,110)
      WRITE(5,109)(NN,COUNT(NN),(PSE(NN,K),K=1,6),NN=1,9)
      WRITE(5,112)
      WRITE(5,109)(NN,COULS(NN),(PSEL(NN,K),K=1,6),NN=1,9)
      WRITE(5,111)
   80 FORMAT(15A1,3I5)
   81 FORMAT(//
     1            ,25X,'DATE=  '15A1,5X,'ITYPE='I3,5X,'NTRAYS='I3,5X,'NMEAS
     1='I3)
   82 FORMAT(F6.2,3F5.2,7X,2F4.1,4F8.1,I3)
   83 FORMAT(6F10.2,I10)
   84 FORMAT(9F8.1)
   85 FORMAT(6F10.0)
   87 FORMAT(2X,I2,2X,5F7.2)
   89 FORMAT(3F10.0)
   90 FORMAT(//,8X,'TNUM='F3.0'   TPOS='F3.0'   DEN='F5.1'   NCLAS='I2'
     1   SDIM='F4.1'   WDIM='F4.1'   LDIM='F4.1'   PDR='F5.3'   SIGD='F5.
     23)
   91 FORMAT(//,32X,'  TNUM='F3.0'   TPOS='F3.0'   DEN='F5.1'   NCLAS='I
     12)
   92 FORMAT(46X,3F7.3,3X,3F7.3,3X,3F7.3)
   93 FORMAT(/,2X,' MEAS TEMPC   RH      UMPS   ESMEA   EQMC          XMCD
     1CMCD   AVMCD    XMCW    CMCW    AVWMC    XMCR    CMCR    AVRMC'/)
   94 FORMAT(//,24X,'          VERTICAL   DRYER                DEN='F5.1'   NCLAS
     1S='I2)
   96 FORMAT (2F10.0,I10,F10.0,I10)
   98 FORMAT(8F10.0)
   99 FORMAT(10X,'          ERROR OF ESTIMATION'7X,2F7.3,10X,2F7.3,10X,2F
     17.3)
  100 FORMAT(/,14X,'   ESTIMATION ERROR OF LAST VALUE'6X,2F7.3,10X,2F7.3,
     1,10X,2F7.3)
  101 FORMAT(/,'   MEAN 'F6.2,4F7.2)
  102 FORMAT(////,4X,' TOTAL NUMBER OF OBSERVATIONS',I5)
  103   FORMAT(/,5X,'          'TOTAL ERROR OF ESTIMATION,  DRY BASIS='F6.3
     1'   WET BASIS='F6.3)
  104 FORMAT (/,5X,'COEFFICIENT OF DETERMINATION, DRY BASIS='F6.3,'   W
     1ET BASIS='F6.3)
  105   FORMAT(/,5X,'NUMBER OF DRYING EXPERIMENTS='I4)
  106 FORMAT(/,5X,'          'ERROR OF ESTIMATED FINAL MOISTURE USING AVE
     1RAGE DAILY CONDITIONS:  D.B.='F6.3,'   W.B.='F6.3)
  107 FORMAT(/,5X,'MEAN MOISTURE CONTENT,   DRY BASIS='F7.3'   WET BASIS
     1='F7.3)
  108 FORMAT(/,5X,'SUM SQUARES DUE TO REGRESSION   D.B.='F8.3'   W.B.=
     1',F8.3,',/,5X, 'TOTAL SUM OF SQUARES,                D.B.='F8.3'   W.B.=
     1'   ,F8.3)
  109 FORMAT(I5,5X,I3,F10.0,F8.3,F7.3,F9.3,F7.3,F8.3,F7.3)
  110 FORMAT(///,5X,'          'ERROR FOR EACH CLASS',/,5X,'NCLAS   COUNT
     1   SECD   SEAVD    SECW   SEAVW    SECR   SEAVR')
  111 FORMAT(////,5X,'***** NORMAL TERMINATION *****')
  112 FORMAT(///,5X,'          'RANGE OF FINAL MOISTURE VALUES FOR EACH CL
     1ASS',/,5X,'NCLAS   COULS   FECD   FEAVD    FECW   FEAVW    FECR   F
     1EAVR')
  120 FORMAT(1H1)
      CALL EXIT
      END
```

DATE= AUG 31 1972 ITYPE= 2 NTRAY= 5 NMEAS= 5

TNUM= 1. TPOS= 2. DEN= 20.0 NCLAS= 2 SDIM= 1.0 WDIM= 1.0 LDIM= 5.0 POR=0.511 SIGD=2.040

MEAS	TEMPC	RH	UMPS	ESMEA	EQMC	XMCD	CMCD	AVMCD	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
						1.673	1.673	1.673	0.625	0.625	0.625	1.000	1.000	1.000
1	30.50	56.00	0.97	14.40	11.15	1.581	1.558	1.536	0.612	0.609	0.605	0.941	0.926	0.912
2	31.00	48.00	0.97	17.51	10.23	1.418	1.426	1.404	0.586	0.587	0.584	0.837	0.842	0.828
3	33.00	40.00	0.82	22.63	9.23	1.295	1.269	1.279	0.564	0.559	0.561	0.761	0.744	0.749
4	32.00	54.00	1.18	16.39	10.80	1.163	1.156	1.161	0.537	0.536	0.537	0.674	0.669	0.674
5	30.00	50.00	1.49	15.90	10.52	1.061	1.049	1.051	0.514	0.512	0.512	0.609	0.602	0.604
MEAN	31.30	49.59	1.09	17.26	10.38									
		ESTIMATION ERROR OF LAST VALUE					0.011	0.009		0.002	0.002		0.007	0.005
		ERROR OF ESTIMATION					0.017	0.022		0.003	0.003		0.010	0.014

TNUM= 5. TPOS= 2. DEN= 20.0 NCLAS= 2 SDIM= 1.0 WDIM= 1.0 LDIM= 5.0 POR=0.511 SIGD=2.040

MEAS	TEMPC	RH	UMPS	ESMEA	EQMC	XMCD	CMCD	AVMCD	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
						1.714	1.714	1.714	0.631	0.631	0.631	1.000	1.000	1.000
1	30.50	56.00	0.97	14.40	11.15	1.581	1.598	1.575	0.612	0.615	0.611	0.917	0.927	0.913
2	31.00	48.00	0.97	17.51	10.23	1.459	1.464	1.442	0.593	0.594	0.590	0.841	0.844	0.831
3	33.00	40.00	0.82	22.63	9.23	1.336	1.305	1.315	0.572	0.566	0.568	0.767	0.747	0.752
4	32.00	54.00	1.18	16.39	10.80	1.204	1.190	1.195	0.546	0.543	0.544	0.682	0.673	0.677
5	30.00	50.00	1.49	15.90	10.52	1.102	1.080	1.083	0.524	0.519	0.519	0.619	0.606	0.608
MEAN	31.30	49.59	1.09	17.26	10.38									
		ESTIMATION ERROR OF LAST VALUE					0.021	0.018		0.004	0.004		0.013	0.011
		ERROR OF ESTIMATION					0.019	0.015		0.003	0.003		0.012	0.009

TNUM= 2. TPOS= 2. DEN= 20.0 NCLAS= 2 SDIM= 1.0 WDIM= 1.0 LDIM= 5.0 POR=0.511 SIGD=2.040

MEAS	TEMPC	RH	UMPS	ESMEA	EQMC	XMCD	CMCD	AVMCD	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
						2.265	2.265	2.265	0.694	0.693	0.693	1.000	1.000	1.000
1	30.50	56.00	0.97	14.40	11.15	2.122	2.143	2.119	0.679	0.681	0.679	0.933	0.943	0.932
2	31.00	48.00	0.97	17.51	10.23	1.959	1.997	1.972	0.662	0.666	0.663	0.858	0.876	0.864
3	33.00	40.00	0.82	22.63	9.23	1.795	1.820	1.828	0.642	0.645	0.646	0.783	0.795	0.797
4	32.00	54.00	1.18	16.39	10.80	1.622	1.662	1.686	0.618	0.627	0.627	0.701	0.730	0.732
5	30.00	50.00	1.49	15.90	10.52	1.439	1.548	1.549	0.598	0.607	0.607	0.640	0.667	0.668
MEAN	31.30	49.59	1.09	17.26	10.38									
		ESTIMATION ERROR OF LAST VALUE					-0.056	-0.053		-0.008	-0.009		-0.026	-0.027
		ERROR OF ESTIMATION					0.043	0.041		0.006	0.006		0.020	0.019

TNUM= 4. TPOS= 2. DEN= 20.0 NCLAS= 2 SDIM= 1.0 WDIM= 1.0 LDIM= 5.0 POR=0.511 SIGD=2.040

MEAS	TEMPC	RH	UMPS	ESMEA	EQMC	XMCD	CMCD	AVMCD	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
						2.071	2.071	2.071	0.674	0.674	0.674	1.000	1.000	1.000
1	30.50	56.00	0.97	14.40	11.15	1.926	1.949	1.925	0.658	0.660	0.658	0.927	0.937	0.925
2	31.00	48.00	0.97	17.51	10.23	1.785	1.805	1.781	0.641	0.643	0.640	0.854	0.865	0.852
3	33.00	40.00	0.82	22.63	9.23	1.632	1.631	1.640	0.623	0.620	0.621	0.778	0.777	0.781
4	32.00	54.00	1.18	16.39	10.80									

5	30.00	50.00	1.49	15.90	10.52	1.469	1.500	1.504	0.595	0.600	0.600	0.693	0.709	0.712
						1.346	1.372	1.374	0.573	0.578	0.578	0.631	0.644	0.645
MEAN	31.30	49.59	1.09	17.26	10.38									
				ESTIMATION ERROR OF LAST VALUE		-0.025	-0.027			-0.004	-0.004		-0.012	-0.014
				ERROR OF ESTIMATION		0.022	0.020			0.003	0.003		0.011	0.010

TNUM= 3. TPOS= 2. DEN= 20.0 NCLAS= 9 SDIM= 1.0 WDIM= 1.0 LDIM= 5.0 POR=0.511 SIGD=2.040

MEAS	TEMPC	RH	UMPS	ESMEA	EQMC	XMCD	CMCD	AVMCD	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
1	30.50	56.00	0.97	14.40	11.15	2.285	2.285	2.285	0.695	0.695	0.695	1.000	1.000	1.000
2	31.00	48.00	0.97	17.51	10.23	2.142	2.109	2.155	0.681	0.684	0.683	0.934	0.946	0.940
3	33.60	40.00	0.82	22.63	9.23	2.000	2.051	2.029	0.666	0.672	0.669	0.869	0.892	0.882
4	32.00	54.00	1.18	16.39	10.80	1.877	1.941	1.908	0.652	0.660	0.656	0.813	0.843	0.827
5	30.00	50.00	1.49	15.90	10.52	1.734	1.818	1.791	0.634	0.645	0.641	0.746	0.785	0.773
						1.632	1.680	1.678	0.620	0.626	0.626	0.706	0.725	0.721
MEAN	31.30	49.59	1.09	17.26	10.38									
				ESTIMATION ERROR OF LAST VALUE		-0.047	-0.046			-0.006	-0.006		-0.021	-0.021
				ERROR OF ESTIMATION		0.037	0.038			0.007	0.007		0.026	0.017

DATE= JUN 2 1973 EXPER= 4 [illegible] NMEAS= 9

VERTICAL DRYER DENS= 24.4 NCLASS= 5

MEAS	TEMPC	RH	DEPS	ESMEA	EQMC	XMCG	CMCG	AVMC	XMCW	CMCW	AVWMC	XMCR	CMCR	AVRMC
1	23.50	81.67	0.51	3.97	18.99	0.626	0.826	0.826	0.393	0.385	0.385	1.000	1.000	1.000
2	26.50	68.60	0.61	8.14	13.60	0.604	0.601	0.597	0.376	0.375	0.359	0.948	0.941	0.863
3	29.00	61.03	0.77	11.70	11.95	0.559	0.557	0.496	0.350	0.357	0.331	0.863	0.857	0.743
4	31.00	58.28	1.02	14.05	11.40	0.485	0.500	0.442	0.325	0.333	0.306	0.720	0.751	0.636
5	31.00	56.90	1.64	14.51	11.22	0.436	0.440	0.395	0.305	0.305	0.283	0.628	0.636	0.543
6	31.00	57.59	1.44	14.28	11.31	0.373	0.384	0.354	0.271	0.277	0.261	0.506	0.529	0.462
7	31.50	55.53	2.10	15.41	11.02	0.320	0.338	0.319	0.242	0.252	0.241	0.404	0.438	0.392
8	31.50	55.53	3.39	15.41	11.02	0.276	0.295	0.288	0.216	0.227	0.223	0.321	0.357	0.332
9	30.00	60.34	2.82	12.61	11.77	0.246	0.256	0.262	0.196	0.204	0.207	0.263	0.283	0.280
MEAN	29.44	61.72	1.59	11.79	12.02	0.242	0.231	0.240	0.195	0.188	0.193	0.245	0.223	0.236

ESTIMATION ERROR OF LAST VALUE 0.010 0.002 0.007 0.001 0.021 0.008
ERROR OF ESTIMATION 0.012 0.003 0.006 0.015 0.023 0.065

A6

TOTAL NUMBER OF OBSERVATIONS 34

MEAN MOISTURE CONTENT, DRY BASIS= 1.273 WET BASIS= 0.560

SUM SQUARES DUE TO REGRESSION D.B.= 0.033 W.B.= 0.001
TOTAL SUM OF SQUARES, D.B.= 11.938 W.B.= 0.873

COEFFICIENT OF DETERMINATION, DRY BASIS= 0.997 WET BASIS= 0.998

TOTAL ERROR OF ESTIMATION, DRY BASIS= 0.031 WET BASIS 0.005

NUMBER OF DRYING EXPERIMENTS= 6

ERROR OF ESTIMATED FINAL MOISTURE USING AVERAGE DAILY CONDITIONS, D.B.= 0.033

ERROR FOR EACH CLASS

NCLAS	COUNT	SECD	SEAVD	SECW	SEAVW	SECR	SEAVR
1	0.	0.000	0.000	0.000	0.000	0.000	0.000
2	20.	0.027	0.027	0.004	0.004	0.014	0.014
3	0.	0.000	0.000	0.000	0.000	0.000	0.000
4	0.	0.000	0.000	0.000	0.000	0.000	0.000
5	0.	0.000	0.000	0.000	0.000	0.000	0.000
6	9.	0.012	0.033	0.006	0.015	0.023	0.065
7	0.	0.000	0.000	0.000	0.000	0.000	0.000
8	0.	0.000	0.000	0.000	0.000	0.000	0.000
9	5.	0.057	0.038	0.007	0.004	0.026	0.017

ERROR OF FINAL MOISTURE VALUES FOR EACH CLASS

NCLAS	COULS	FECD	FEAVD	FECW	FEAVW	FECR	FEAVR
1	0.	0.000	0.000	0.000	0.000	0.000	0.000
2	4.	0.033	0.034	0.005	0.005	0.016	0.016
3	0.	0.000	0.000	0.000	0.000	0.000	0.000
4	0.	0.000	0.000	0.000	0.000	0.000	0.000
5	0.	0.000	0.000	0.000	0.000	0.000	0.000
6	1.	0.010	0.002	0.007	0.001	0.021	0.008
7	0.	0.000	0.000	0.000	0.000	0.000	0.000
8	0.	0.000	0.000	0.000	0.000	0.000	0.000
9	1.	0.047	0.046	0.006	0.006	0.021	0.021

***** NORMAL TERMINATION *****

```
C*****
C*****
C***** PROGRAM TO SIMULATE NATURAL DRYING OF CASSAVA USING SIX
C***** DRYING SYSTEMS
C*****
C*****      NN=1 VERTICAL TRAYS WITH 0.8 X 0.8 X 5.0 RECTANGULAR BARS
C*****      NN=2 VERTICAL TRAYS WITH 1.0 X 1.0 X 5.0 RECTANGULAR BARS
C*****      NN=3 VERTICAL TRAYS WITH 1.2 X 1.2 X 5.0 RECTANGULAR BARS
C*****      NN=4 HORIZONTAL TRAYS WITH 1.0 X 1.0 X 5.0 RECTANGULAR BARS
C*****      NN=5 VERTICAL TRAYS WITH BARS PRODUCED BY A DISC CUTTER
C*****      NN=6 VERTICAL DRYER WITH WINGS AND BARS PRODUCED
C*****           BY A DISC CUTTER
C*****
C***** VARIABLES
C*****
C*****         1- FRESH WEIGHT PER SQUARE METER OF THE DRIER
C*****         2- WIND VELOCITY
C*****         3- AIR TEMPERATURE
C*****         4- AIR RELATIVE HUMIDITY
C*****
C*****
      REAL LDIM(10),LL,LD
      [illegible]
     1[illegible],CMCD(10),UMPS(20),PS(20)
      DIMENSION SDIM(10),WDIM(10),CMCD(10),CMCW(10)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD,VS
      SS=0.
      LL=0.
      WW=0.
      WRITE(5,120)
      DO 11 J=1,2
      LDIM(J)=5.
      SDIM(J)=(J-.2
      WDIM(J)=SDIM(J)
      LL=LDIM(J)+LL
      SS=SDIM(J)*SDIM(J)
      WW=SS
      SIGD(J)=1./SS+1./WW+1./LL
   11 POR(J)=(.420+.0166*LDIM(J))*(1.1609-.144*SDIM(J))
      DEN1=10.
      DO 10 J=1,2
      DEN(J)=DEN1+15.
      DEN1=DEN(J)
      UM=1.5
      I=0
      TEM=5.
      DO 10 ITEMP=1,2
      TEM=TEM+10.
      RU=.7
      I=I+1
      RH=RU*100.
      UMPS(I)=UM
      TEMPC(I)=TEM
      RH(I)=RU
      DO 13 N=1,9
      CMCD(N)=2.0
      CMCD1(N)=2.0
   13 CMCW(N)=CMCD(N)/(1.+CMCD(N))
      CALL VPDIF(I)
      CALL EQUIL(I)
      EQMC(I)=EQMC(I)*100.
      WRITE(5,80)DEN(J    ),UM,TEM,RH,ESMEA(I),EQ
      WRITE(5,82)
      WRITE(5,81)
      WRITE(5,83)(CMCD(NN),NN=1,6)
      DO 10 IHOUR=1,14
      IHM=IHOUR-1
      IF(IHOUR-1)14,15,14
   14 WRITE(5,85)IHM ,(CMCD(NN),NN=1,6)
   15 CONTINUE
      DO 10 NM=1,6
      GO TO (21,22,23,24,25,26),NM
   21 NN=1
      IDEN=1
      GO TO 29
   22 NN=1
      IDEN=2
      GO TO 29
   23 NN=1
      IDEN=3
      GO TO 29
   24 NN=2
      IDEN=2
      GO TO 29
```

```
 25 NN=3
    IDEN=1
    GO T O 29
 26 NN=6
    IDEN=1
 29 CONTINUE
    CALL LAYEQ (I,IDEN,NN,CM,J,NM)
    CMCD(NM)=CM
 10 CONTINUE
 80 FORMAT(1X,/,  ' DEN='F5.1'   UMPS='F4.1'   TEMPC='F4.1'   RH='F6.3
   1 '  ESMEA='F5.2'   EQMC='F6.3)
 81 FORMAT(1X,/,'  HRS  NN=1          NN=2          NN=3          NN=4
   1   NN=5          NN=6 ')
 82 FORMAT(/,14X,'SIMULATED MOISTURE CONTENT, DRY BASIS, DECIMAL')
 83 FORMAT(7X,9(F5.3,7X))
 85 FORMAT(1X,I3,3X,6(F5.3,7X))
120 FORMAT(1H1)
    CALL EXIT
    END
```

DEN= 25.0 UMPS= 1.5 TEMPC=15.0 RH=70.000 ESMEA= 3.83 EQMC=14.933

SIMULATED MOISTURE CONTENT, DRY BASIS, DECIMAL

HRS	NN=1	NN=2	NN=3	NN=4	NN=5	NN=6
	2.000	2.000	2.000	2.000	2.000	2.000
1	1.766	1.854	1.906	1.956	1.941	1.920
2	1.556	1.719	1.816	1.913	1.882	1.840
3	1.373	1.593	1.730	1.871	1.823	1.762
4	1.210	1.475	1.648	1.830	1.764	1.684
5	1.067	1.366	1.570	1.789	1.706	1.607
6	0.941	1.265	1.495	1.748	1.648	1.531
7	0.832	1.171	1.424	1.708	1.591	1.457
8	0.737	1.085	1.356	1.669	1.535	1.385
9	0.654	1.005	1.291	1.631	1.479	1.315
10	0.583	0.932	1.229	1.593	1.425	1.248
11	0.521	0.864	1.170	1.556	1.371	1.182
12	0.468	0.802	1.115	1.519	1.319	1.119
13	0.423	0.745	1.062	1.483	1.268	1.059

DEN= 25.0 UMPS= 1.5 TEMPC=25.0 RH=70.000 ESMEA= 7.12 EQMC=14.085

SIMULATED MOISTURE CONTENT, DRY BASIS, DECIMAL

HRS	NN=1	NN=2	NN=3	NN=4	NN=5	NN=6
	2.000	2.000	2.000	2.000	2.000	2.000
1	1.738	1.837	1.895	1.939	1.923	1.903
2	1.505	1.685	1.794	1.879	1.846	1.824
3	1.299	1.544	1.698	1.821	1.767	1.734
4	1.119	1.413	1.606	1.763	1.688	1.642
5	0.964	1.291	1.519	1.706	1.609	1.550
6	0.831	1.180	1.435	1.650	1.530	1.458
7	0.717	1.078	1.355	1.596	1.452	1.368
8	0.621	0.984	1.280	1.542	1.375	1.279
9	0.540	0.899	1.208	1.490	1.300	1.192
10	0.472	0.821	1.141	1.438	1.226	1.109
11	0.415	0.751	1.076	1.388	1.155	1.029
12	0.368	0.688	1.016	1.340	1.086	0.953
13	0.328	0.630	0.959	1.292	1.019	0.881

DEN= 40.0 UMPS= 1.5 TEMPC=15.0 RH=70.000 ESMEA= 3.83 EQMC=14.984

SIMULATED MOISTURE CONTENT, DRY BASIS, DECIMAL

HRS	NN=1	NN=2	NN=3	NN=4	NN=5	NN=6
	2.000	2.000	2.000	2.000	2.000	2.000
1	1.842	1.902	1.937	1.972	1.965	1.952
2	1.696	1.810	1.876	1.935	1.930	1.905
3	1.561	1.721	1.818	1.897	1.895	1.852
4	1.436	1.636	1.760	1.860	1.860	1.812
5	1.320	1.555	1.705	1.823	1.825	1.755
6	1.214	1.478	1.651	1.787	1.791	1.714
7	1.117	1.405	1.598	1.752	1.756	1.673
8	1.028	1.335	1.548	1.717	1.722	1.627
9	0.946	1.269	1.493	1.683	1.687	1.582
10	0.872	1.206	1.451	1.649	1.653	1.538
11	0.804	1.146	1.404	1.616	1.620	1.494
12	0.742	1.090	1.360	1.584	1.588	1.451
13	0.686	1.036	1.316	1.553	1.553	1.408

DEN= 40.0 UMPS= 1.5 TEMPC=25.0 RH=70.000 ESMEA= 7.12 EQMC=14.065

SIMULATED MOISTURE CONTENT, DRY BASIS, DECIMAL

HRS	NN=1	NN=2	NN=3	NN=4	NN=5	NN=6
	2.000	2.000	2.000	2.000	2.000	2.000
1	1.823	1.891	1.930	2.000	1.955	1.949
2	1.660	1.787	1.892	2.000	1.909	1.897
3	1.508	1.687	1.796	2.000	1.863	1.845
4	1.369	1.593	1.732	2.000	1.817	1.791
5	1.241	1.502	1.669	2.000	1.771	1.738
6	1.125	1.416	1.609	2.000	1.724	1.684
7	1.019	1.332	1.550	2.000	1.677	1.629
8	0.923	1.257	1.493	2.000	1.630	1.575
9	0.837	1.184	1.438	2.000	1.584	1.521
10	0.759	1.115	1.385	2.000	1.537	1.466
11	0.689	1.050	1.334	2.000	1.491	1.413
12	0.627	0.989	1.284	2.000	1.445	1.359
13	0.571	0.932	1.236	2.000	1.399	1.307

```
C*****
C*****
C***** SUBROUTINE TO CALCULATE THE MAXIMUM LAYER DENSITY THAT CAN SAFELY
C***** BE DRIED AS A FUNCTION OF THE WEATHER CONDITIONS AND THE DRYING
C***** SYSTEM
C*****
C*****
C*****
      SUBROUTINE CRITD(I,NN,J,CMC,DRT,CRTD)
      DATA PAR1,PAR2,PAR3,PAR4/.04757,.01809,-.00231,.00292,1.53686,-.02
     12139,-1.06337,1.86295,.52454,-.0026,.01186,-.00184,.00692,2.39961,
     2-.061475,-.80926,2.66468,.21248,-.01382,.02[illegible],-.00313,.01312,1.55
     3848,-.025258,1.0,0.0,0.0,-.00462,-.00106,-.00217,.00061,2.048,-.05
     125,1.0,0.0,0.0/
      DATA PAR5,PAR6,PAR7,PAR8,PAR9/-.02317,.05345[illegible],.010067,1.
     17091,-.0277,1.,0.,0.,.0178,.0144,-.005,.01278,1.7894,-.0277,1.,0.
     2,0.0,.07024,.0[illegible],-.0007216[illegible],.[illegible],3.25[illegible],-.140855,1.0,0.
     30,0.0,.12786,.047[illegible],-.00216[illegible],.[illegible],.0546239,1.0,0
     4.0,0.0,.00766,.041716,-.0009126[illegible],.0025695,2.[illegible],-.0837894,1.0,0.
     5,0.0/
      DIMENSION PAR(9,9),PAR1(9),PAR2(9),PAR3(9),PAR4(9),PAR5(9),PAR6(9,
     1),PAR7(9),PAR8(9),PAR9(9)
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIG(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIG,CMCD1,PS
      IF(IFLAG-2)5,6,5
    5 CONTINUE
      DO 10 L=1,9
      PAR(L,1)=PAR1(L)
      PAR(L,2)=PAR2(L)
      PAR(L,3)=PAR3(L)
      PAR(L,4)=PAR4(L)
      PAR(L,5)=PAR5(L)
      PAR(L,6)=PAR6(L)
      PAR(L,7)=PAR7(L)
      PAR(L,8)=PAR8(L)
      PAR(L,9)=PAR9(L)
   10 CONTINUE
    6 CONTINUE
      B0=(PAR(1,NN)+PAR(2,NN)*UMPS(I)+PAR(4,NN)*(ESMEA(I))*EQMC(I)
      B1=-PAR(1,NN)-PAR(2,NN)*UMPS(I)-PAR(4,NN)*ESMEA(I)+PAR(3,NN)*ESMEA
     1(I)*EQMC(I)
      B2=-PAR(3,NN)*ESMEA(I)
      B3=PAR(7,NN)+PAR(8,NN)*POR(J)+PAR(9,NN)*SIG(J)
      C1=.5*(B1/B2-SQRT((B1/B2)*(B1/B2)-4.*B0/B2))
      C0=B1/B2-C1
      C2=B2*B3*PAR(5,NN)
      C3=B2*B3*PAR(6,NN)
      CRTD= ALOG((CMC+C0)*(2.*C1)/((CMC+C1)*(2.*C0)))/(C1*C3-C0*C3)*(
     1)-C2/C3
      EQM=EQMC(I)
      IF(EQM-.15)12,12,11
   11 CMC=1.2*EQM
      GO TO 13
   12 CMC=.15
   13 CONTINUE
      TOTH=ALOG((CMC+C0)*(2.*C1)/((CMC+C1)*(2.*C0)))/((C1-C0)*(C2*C3*DRT
     1D))
      DRT=TOTH/DRT
      IFLAG=2
      RETURN
      END
```

```
C*****
C*****
C*****
C***** PROGRAM TO TEST THE FOLLOWING DRYING SYSTEMS FOR
C***** MAXIMUM DENSITY PERMISSIBLE
C*****
C*****     N=1 VERTICAL TRAY WITH 0.8X0.8X5.0 RECTANGULAR BARS
C*****     N=2 VERTICAL TRAY WITH 1.0X1.0X5.0 RECTANGULAR BARS
C*****     N=3 VERTICAL TRAY WITH 1.2X1.2X5.0 RECTANGULAR BARS
C*****     N=4 HORIZONTAL TRAY WITH 1.0X1.0X5.0 RECTANGULAR BARS
C*****     N=5 VERTICAL TRAY WITH BARS PRODUCED BY A DISC CUTTER
C*****     N=6 VERTICAL DRYER WITH WINGS AND BARS PRODUCED
C*****         BY A DISC CUTTER
C*****
C*****     N=1,2,3,4,5,6 SAME AS ABOVE WITH CASSAVA PARTICLES DIPPED IN
C*****     A 50 PER CENT ALCOHOL SOLUTION FOR 2 MIN.
C*****
C*****     OUTPUT SYMBOLOGY
C*****
C*****     UMPS= WIND VELOCITY IN METERS PER SECOND
C*****     TEMPC= AIR DRY BULB TEMPERATURE IN DEGREES CENTIGRADE
C*****     RH= RELATIVE HUMIDITY IN PERCENT
C*****     ESMEA= SATURATED VAPOR PRESSURE DEFICIT
C*****     EQMC= CASSAVA EQUILIBRIUM MOISTURE CONTENT,D.B., PER
C*****     EQP20 = 1.2 X EQMC
C*****
      DATA ARST,SD,LD,LL/6.,7.,8.,9.,10.,11.,12.,13.,4.,5.,6.,7./
      REAL LDIM(10)
      REAL LL,LD
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20,10,10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      DIMENSION CRD(14),SDIM(10),WDIM(10),
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      I=0
      WRITE(5,120)
      DO 9 J=1,3
      LDIM(J)=5.
      SDIM(J)=SD+.2
      WDIM(J)=SDIM(J)
      SD=SDIM(J)
      SS=SDIM(J)*SDIM(J)
      WW=SS
      SIGD(J)=1./SS+1./WW+1./LL
    9 POR(J)=(.42+.0166*LDIM(J))*(1.1009-.1441*SDIM(J))
      UM=-.5
      DO 10 IUM=1,2
      UM=UM+1.
      TEM=5.
      DO 10 ITEM=1,3
      TEM=TEM+10.
      RU=.7
      RU100=RU*100.
      I=I+1
      RH(I)=RU
      TEMPC(I)=TEM
      UMPS(I)=UM
      CALL VPDIF(I)
      CALL EQEQ(I)
      EQ100=EQMC(I)*100.
      WRITE(5,84)
      EQP20=EQ100*1.2
      WRITE(5,83)UM,TEM,RU100,ESMEA(I),EQ100,EQP20
      WRITE(5,82)
      WRITE(5,81)
      DTT=5.
      DO 10 IHOUR=1,9
      IF(IHOUR-1)4,5,4
    4 WRITE(5,80)DTT,(CRD(N),N=1,12)
    5 CONTINUE
      DTT=DTT+1.
      DO 10 N=1,12
      GO TO (11,12,13,14,15,17,18,19,30,31,32,34),N
   11 NN=1
      J=1
      CMC=1.
      GO TO 35
   12 NN=1
      J=2
      CMC=1.
      GO TO 35
   13 NN=1
      J=3
      CMC=1.0
```

A10

```
      GO TO 35
14    NN=2
      J=2
      CMC=1.
      GO TO 35
15    NN=3
      J=1
      CMC=1.
      GO TO 35
17    NN=6
      J=1
      CMC=1.0
      GO TO 35
18    NN=4
      J=1
      CMC=1.0
      GO TO 35
19    NN=1
      J=2
      CMC=-1.2
      GO TO 35
20    NN=1
      J=3
      CMC=1.0
      GO TO 35
21    NN=2
      J=1
      CMC=1.
      GO TO 35
2     J=3
      CMC=1.2
      GO TO 35
24    NN=6
      J=1
      CMC=1.0
35    CONTINUE
      DO 37
      CALL CR1*0(I,NN,J,CMC,DI,DO)
      IF(DO.LT.0.21,2%
70    DO 0.
      DI=10.**20
      CONTINUE
      DO 1X.EQ.0
      CONTINUE
      WRITE(   NO.    NO.        NO.    N        NO.        NO.
     1    N=1    NO.2
      FORMAT(1X,F4.0,6F8.
      FORMAT(/,2X,
      FORMAT(11X,'
     2    (2X,F8.2,2X,
      FORMAT(/,2X,'NUMBER OF ITERATIONS (NO.SAME
      FORMAT(1X,///)
      END SAI
```

A11

```
C******
C******
C***** MAIN PROGRAM TO CALCULATE SENSITIVITY COEFFICIENTS OF THE
C***** MAXIMUM LAYER DENSITY THAT CAN SAFELY BE DRIED AS A FUNCTION
C***** OF WEATHER VARIABLES AND GEOMETRIC PROPERTIES OF CASSAVA
C***** RECTANGULAR BARS
C*****
C***** THE SENSITIVITY COEFFICIENTS ARE EVALUATED AT DIFFERENT
C***** AND REPRESENTATIVE WEATHER CONDITIONS AND FOR FIVE
C***** DRYING SYSTEMS
C*****
C***** THE SYSTEMS ARE
C*****
C*****      NCLAS=1 VERTICAL TRAYS WITH 1.2X1.2X(1.5,5.0)
C*****              CASSAVA RECTANGULAR BARS
C*****      NCLAS=2 HORIZONTAL TRAYS WITH 1.2X1.2X(1.5,5.0)
C*****              CASSAVA RECTANGULAR BARS
C*****      NCLAS=3 VERTICAL TRAYS WITH BARS PRODUCED BY A DISC CUTTER
C*****
C*****      NCLAS=6 VERTICAL DRYER WITH BARS PRODUCED BY A DISC CUTTER
C*****
C*****    OUTPUT SYMBOLOGY
C*****
C*****          W2XW2= SECTION OF THE RECTANGULAR BAR
C*****          W1= LENGTH OF THE RECTANGULAR BAR
C*****          UMPS= WIND VELOCITY IN METERS PER SECOND
C*****          RH= RELATIVE HUMIDITY, PER CENT
C*****          TEMPC= AIR TEMPERATURE IN DEGREES CENTIGRADE
C*****
C*****      SENSITIVITY COEFFICIENTS
C*****
C*****          SCW2= W2X(DEN2-DEN1)/(W22-W21)
C*****          SCW1= W1X(DEN2-DEN1)/(W12-W11)
C*****          SCU= UMPSX(DEN2-DEN1)/(UMPS2-UMPS1)
C*****          SCTAH= TEMPCX(DEN2-DEN1)/(TEMPC2-TEMPC1)
C*****
C*****
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(10),
     1POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      W2=1.2
      WRITE(5,120)
      DO 10 N=1,6
      IF(N-4)6,10,6
    6 CONTINUE
      WRITE(5,83)N
      WRITE(5,80)
      IF(N-2)1,1,2
    1 WRITE(5,81)
      NID=2
      GO TO 3
    2 WRITE(5,84)
      NID=1
    3 CONTINUE
      W1=-2.
      DO 10 IDEM=1,NID
      I=0
      W1=W1+3.5
      UM=-.5
      DO 10 IUM=1,2
      UM=UM+1.
      RU=.7
      RU100=RU*100.
      TEM=15.
      DO 10 ITEM=1,2
      TEM=TEM+10.
      I=I+1
      UMPS(I)=UM
      TEMPC(I)=TEM
      RH(I)=RU
      CALL DIMEQ(1,W1,W2)
      CALL ESEQ(I)
      CALL VPDIF(I)
      SMA=ESMEA(I)
      SATP=PS(I)
      CMC=1.
      DRT=10.
      CALL CRITD(I,N,1,CMC,DRT,CD1)
      W1=W1+.05
      CALL DIMEQ(1,W1,W2)
      CMC=1.
      DRT=10.
      CALL CRITD(I,N,1,CMC,DRT,CD)
      W1=W1-.05
```

A12

```
      CALL DIMEQ(1,W1,W2)
      SCW1=W1*(CD1-CD)/.05
      W2=W2+.05
      CALL DIMEQ(1,W1,W2)
      CMC=1.
      DRT=10.
      CALL CRITD(I,N,1,CMC,DRT,CD)
      W2=W2-.05
      CALL DIMEQ(1,W1,W2)
      SCW2=W2*(CD1-CD)/.05
      UMPS(I)=UMPS(I)-.1
      CMC=1.
      DRT=10.
      CALL CRITD(I,N,1,CMC,DRT,CD)
      UMPS(I)=UMPS(I)+.1
      SCU=UMPS(I)*(CD1-CD)/.1
      TEMPC(I)=TEMPC(I)-.1
      CALL VPDIF(I)
      ESMEA(I)=SMA+51.71*(PS(I)-SATP)
      RH(I)=(PS(I)-ESMEA(I)/51.71)/PS(I)
      CALL EQEQ(I)
      CMC=1.
      DRT =10.
      CALL CRITD(I,N,1,CMC,DRT,CD)
      SCTAH=TEM*(CD1-CD)/.1
      TEMPC(I)=TEMPC(I)+.1
      IF(N-2)4,4,5
    4 WRITE(5,82)W2,W1,UM,RU100,TEM,SCW2,SCW1,SCU,SCTAH
      GO TO 10
    5 WRITE(5,85)UM,RU100,TEM,SCU,SCTAH
   10 CONTINUE
   80 FORMAT(  /,16X,' VARIABLES ',35X,'SENSITIVITY COEFFICIENTS OF MAXI
     *MUM ALLOWED DENSITY ')
   81 FORMAT(  /6X,'W2',6X,'W1',9X,'UMPS',4X,'RH',6X,'TEMPC',17X,'SCW2',
     *11X,'SCW1',14X,'SCU',11X,'SCTAH'/)
   82 FORMAT( 3X,2(F6.3,2X),5X,3(F5.2,3X),8X,4(4X,F8.3,4X)  )
   83 FORMAT(    ///,50X,'NCLAS=',I2)
   84 FORMAT(  /13X,'UMPS',4X,'RH',5X,'TEMPC',4X,'SCU',13X,'SCTAH'/)
   85 FORMAT(12X,3(F6.2,3X),35X,2(4X,F6.3,4X))
  120 FORMAT(1H1)
      CALL EXIT
      END
```

A13

```
C*****
C*****
C*****  SUBROUTINE TO CALCULATE SELECTED GEOMETRIC PROPERTIES OF CASSAVA
C*****  RECTANGULAR BARS
C*****
C*****
      SUBROUTINE DIMEQ(J,W1,W2)
      DIMENSION TEMPC(20),RH(20),ESMEA(20),EQMC(20),XMCD(20,10),DEN(20
     1),POR(10),SIGD(10),CMCD1(10),UMPS(20),PS(20)
      COMMON TEMPC,RH,UMPS,ESMEA,EQMC,XMCD,DEN,POR,SIGD,CMCD1,PS
      S1=W1*W1
      S2=W2*W2
      S3=S2
      SIGD(J)=1./S1+1./S2+1./S3
      POR(J)=   (.42+.0166*W1)*(1.1609-.144*W2)
      RETURN
      END
```

VARIABLES

W2	W1	UMPS	RH	TEMPC
1.1000	1.1500	0.1500	70.000	25.000
1.1500	1.1750	0.2000	72.500	27.500
1.2000	1.2000	0.2500	75.000	30.000
1.2500	1.2250	0.3000	77.500	32.500
1.3000	1.2500	0.3500	80.000	35.000
1.3500	1.2750	0.4000	82.500	37.500
1.4000	1.3000	0.4500	85.000	40.000
1.4500	1.3250	0.5000	87.500	42.500
1.5000	1.3500	0.5500	90.000	45.000

NCLASS 2

SENSITIVITY COEFFICIENTS OF MAXIMUM ALLOWED DENSITY

SCW1	SCU	SCTAM
7.6636	9.4995	238.234
4.4562	3.1302	168.765
5.8613	14.8806	111.555
3.1004	6.4409	122.665
-11.2301	8.5394	218.724
-14.3334	2.9023	170.309
-8.2240	15.9021	120.485
-5.1443	5.8884	119.050

NCLASS 3

SENSITIVITY COEFFICIENTS OF MAXIMUM ALLOWED DENSITY

SCU	SCTAM
34.511	462.730
10.037	334.656
34.305	111.498
14.339	167.492

VARIABLES

UMPS	RH	TEMPC
0.150	70.00	25.00
0.200	72.50	27.50
0.250	75.00	30.00
0.300	77.50	32.50
0.350	80.00	35.00
0.400	82.50	37.50
0.450	85.00	40.00
0.500	87.50	42.50
0.550	90.00	45.00

NCLASS 5

SENSITIVITY COEFFICIENTS OF MAXIMUM ALLOWED DENSITY

SCU	SCTAM
157.655	493.445
51.167	334.624
35.384	67.782
23.260	83.052

VARIABLES

UMPS	RH	TEMPC
0.150	70.00	25.00
0.200	72.50	27.50
0.250	75.00	30.00
0.300	77.50	32.50
0.350	80.00	35.00
0.400	82.50	37.50
0.450	85.00	40.00
0.500	87.50	42.50
0.550	90.00	45.00

NCLASS 6

APPENDIX B

APPENDIX B

ORIGINAL DATA AND PREDICTED RESULTS

Page

B1 Original Data and Predicted Results 181

B2 Physical Characteristics of Each Drying Test 220

B3 Drying Systems Nomenclature 227

Experimental and Calculated Average Moisture Content Values (August 31, 1972)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 1 $\bar{M}_{exp.}$ d.b.	1 $\bar{M}_{cal.}$ d.b.	5 $\bar{M}_{exp.}$ d.b.	5 $\bar{M}_{cal.}$ d.b.	2 $\bar{M}_{exp.}$ d.b.	2 $\bar{M}_{cal.}$ d.b.	4 $\bar{M}_{exp.}$ d.b.	4 $\bar{M}_{cal.}$ d.b.	3 $\bar{M}_{exp.}$ d.b.	3 $\bar{M}_{cal.}$ d.b.
					1.673	1.673	1.714	1.714	2.265	2.265	2.071	2.071	2.285	2.285
1	30.5	56.0	0.97	69.9										
					1.581	1.558	1.581	1.598	2.122	2.143	1.928	1.949	2.142	2.169
2	31.0	48.0	0.97	65.3										
					1.418	1.426	1.459	1.464	1.959	1.997	1.785	1.805	2.000	2.051
3	33.0	40.0	0.82	68.5										
					1.295	1.269	1.336	1.305	1.795	1.820	1.632	1.631	1.877	1.941
4	32.0	54.0	1.18	58.2										
					1.163	1.156	1.204	1.190	1.622	1.682	1.459	1.500	1.734	1.818
5	30.0	50.0	1.49	42.4										
					1.061	1.049	1.102	1.080	1.489	1.546	1.346	1.372	1.632	1.680
Mean	31.3	49.6	1.09	60.9	Ave. error	0.017		0.019		0.043		0.022		0.057

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (September 1, 1972)**

Hour	Enviromental Conditions				Test Number* 1		5		2		4		3	
	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					0.928	0.928	0.989	0.989	1.357	1.357	1.204	1.204	1.489	1.489
1	24.5	80.0	0.35	25.3										
					0.918	0.906	0.979	0.966	1.336	1.327	1.193	1.176	1.479	1.454
2	25.5	72.0	0.41	39.7										
					0.877	0.873	0.938	0.931	1.285	1.282	1.142	1.135	1.448	1.411
3	28.5	63.0	0.56	61.5										
					0.816	0.821	0.877	0.876	1.204	1.212	1.071	1.071	1.377	1.355
4	31.5	55.0	0.67	51.8										
					0.744	0.750	0.795	0.801	1.112	1.114	0.979	0.982	1.306	1.288
5	32.0	42.0	0.71	55.7										
					0.673	0.664	0.724	0.709	1.010	0.993	0.897	0.872	1.234	1.212
6	32.0	41.0	0.82	56.8										
					0.602	0.585	0.653	0.625	0.918	0.880	0.816	0.770	1.153	1.134
7	32.5	43.0	0.77	41.0										
					0.540	0.516	0.591	0.552	0.826	0.779	0.734	0.681	1.091	1.062
8	30.0	48.0	0.97	25.6										
					0.500	0.468	0.540	0.499	0.765	0.704	0.683	0.615	1.051	0.994
9	28.0	54.0	0.31	9.3										
					0.469	0.436	0.510	0.465	0.724	0.655	0.642	0.572	1.030	0.958
Mean	29.4	55.3	0.62	40.7	Ave. error	0.019		0.026		0.037		0.041		0.037

* Identification of the test number is given in pages 220-226

** Continuation of experiment on August 31.

Experimental and Calculated Average Moisture Content Values (September 2, 1972)**

Enviromental Conditions					Test Number* 1		5		2		4		3	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.377	0.377	0.408	0.408	0.602	0 602	0.540	0 540	0.908	0.908
1	27.0	78.0	0.48	34.3										
					0.357	0.368	0.387	0.397	0.571	0.583	0.510	0.524	0.887	0.881
2	27.5	70.0	0.56	54.0										
					0.316	0.353	0.346	0.381	0.510	0.557	0.448	0.501	0.826	0.848
3	28.0	67.0	0.67	59.6										
					0.285	0.337	0.316	0.363	0.459	0.528	0.408	0.476	0.785	0.812
4	30.5	52.0	0.77	65.4										
					0.234	0.311	0.265	0.334	0.387	0.482	0.346	0.434	0.714	0.766
Mean	28.3	66.8	0.62	53.3	Ave. error	0.050		0.045		0.063		0.061		0.031

* Identification of the test number are given in pages 220-226

** Continuation of experiment on September 1.

Experimental and Calculated Average Moisture Content Values (September 14, 1972)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr		Test Number* 2 $\bar{M}_{exp.}$ d.b.	2 $\bar{M}_{cal.}$ d.b.	6 $\bar{M}_{exp.}$ d.b.	6 $\bar{M}_{cal.}$ d.b.
1	30.0	60.0	1.03	40.3		1.561	1.561	1.704	1.704
2	33.0	53.0	1.15	64.1		1.397	1.398	1.540	1.534
3	33.5	45.0	1.15	49.2		1.132	1.193	1.285	1.316
4	35.0	42.0	1.49	58.0		0.959	0.977	1.102	1.084
5	35.0	40.0	1.61	55.3		0.765	0.764	0.877	0.852
6	33.0	45.0	3.33	28.9		0.622	0.587	0.683	0.656
7	31.5	46.0	3.33	20.3		0.500	0.458	0.551	0.511
						0.438	0.368	0.469	0.409
Mean	33.0	47.3	1.87	45.2	Ave. error	0.041		0.033	

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (September 21, 1972)

Hour	Enviromental Conditions					Test Number* 2		1	
	T	RH	u	R_i		$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$		d.b.	d.b.	d.b.	d.b.
						1.612	1.612	2.051	2.051
1	27.5	80.0	0.62	54.7		1.469	1.541	1.928	1.915
2	28.0	65.0	0.62	65.4		1.306	1.422	1.734	1.771
3	31.0	53.0	0.82	66.6		1.122	1.242	1.551	1.588
4	31.0	53.0	1.08	75.9		0.938	1.071	1.306	1.390
5	32.5	50.0	0.87	66.3		0.775	0.902	1.132	1.224
6	33.5	41.0	0.87	59.3		0.663	0.723	0.979	1.059
7	33.0	45.0	0.97	21.1		0.571	0.589	0.877	0.913
8	31.0	47.0	0.56	16.3		0.520	0.497	0.806	0.817
Mean	30.9	54.2	0.80	53.2	Ave. error	0.094		0.057	

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (September 29, 1972)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 1 $\bar{M}_{exp.}$ d.b.	1 $\bar{M}_{cal.}$ d.b.	2 $\bar{M}_{exp.}$ d.b.	2 $\bar{M}_{cal.}$ d.b.
					1.826	1.826	1.826	1.826
1	32.0	54.0	0.82	67.5				
					1.540	1.616	1.622	1.643
2	33.5	46.0	0.93	70.8				
					1.255	1.364	1.387	1.420
3	35.0	40.0	1.15	67.4	1.000	1.087	1.153	1.171
4	36.5	38.0	1.49	63.4				
					0.775	0.823	0.938	0.923
5	35.0	43.0	2.53	32.1				
					0.612	0.630	0.744	0.734
6	33.0	45.0	2.64	7.1				
					0.520	0.497	0.673	0.597
Mean	34.2	44.3	1.59	51.4	Ave. error	0.068		0.036

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (October 5, 1972)

Hour	Enviromental Conditions				Test Number* 2		5		6	
	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp,}$	$M_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm\ hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					1.969	1.969	2.030	2.030	2.030	2.030
1	30.5	56.0	0.93	61.6	1.714	1.774	1.806	1.859	1.846	1.884
2	31.0	53.0	0.72	67.2	1.438	1.576	1.571	1.684	1.653	1.734
3	33.5	44.0	1.23	68.7	1.122	1.310	1.285	1.443	1.408	1.525
4	35.0	42.0	1.43	58.1	0.867	1.043	1.030	1.192	1.183	1.303
5	34.0	43.0	3.39	50.0	0.673	0.799	0.806	0.951	0.948	1.080
6	33.5	43.0	3.68	30.1	0.540	0.609	0.622	0.753	0.755	0.888
Mean	32.9	46.8	1.90	56.0	Ave. error	0.134		0.132		0.108

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (October 17, 1972)

	Enviromental Conditions				Test Number* 1		2		3		5	
Hour	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					1.734	1.734	1.775	1.775	2.183	2.183	2.163	2.163
1	30.5	52.0	0.85	64.9	1.459	1.535	1.489	1.469	1.928	2.001	1.918	1.891
2	33.0	43.0	0.92	51.8	1.214	1.283	1.244	1.203	1.653	1.757	1.693	1.646
3	34.5	38.1	1.03	53.3	1.03	1.019	1.051	0.972	1.438	1.480	1.489	1.418
4	35.0	34.0	0.77	48.8	0.846	0.783	0.857	0.794	1.224	1.210	1.326	1.232
5	36.0	32.0	0.97	46.3	0.693	0.578	0.693	0.637	1.030	0.950	1.132	1.055
6	35.0	34.0	0.82	31.7	0.581	0.439	0.581	0.519	0.897	0.753	1.00	0.908
Mean	34.0	38.8	0.89	49.5	Ave. error	0.089		0.056		0.087		0.071

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (October 27, 1972)

	Environmental Conditions				Test Number*													
					1		5		6		7		8		4		9	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.877	1.877	2.000	2.000	1.724	1.724	1.744	1.744	1.755	1.755	1.826	1.826	2.000	2.000
1	31.0	52.0	0.93	44.6														
					1.540	1.664	1.734	1.811	1.510	1.570	1.510	1.512	1.571	1.602	1.571	1.604	1.676	1.729
2	33.50	44.0	1.12	66.0														
					1.275	1.393	1.489	1.565	1.326	1.373	1.306	1.295	1.428	1.453	1.367	1.409	1.563	1.670
3	34.0	38.5	1.38	51.6														
					0.989	1.114	1.244	1.303	1.132	1.164	1.112	1.031	1.275	1.305	1.163	1.201	1.479	1.509
4	35.0	38.0	1.32	40.6														
					0.816	0.865	1.051	1.056	0.959	0.960	0.943	0.919	1.142	1.172	0.989	1.027	1.346	1.362
5	36.0	37.0	1.26	41.7														
					0.642	0.653	0.857	0.834	0.816	0.790	0.795	0.774	1.039	1.052	0.795	0.875	1.264	1.253
6	35.0	39.0	2.83	27.6														
					0.519	0.498	0.683	0.648	0.663	0.637	0.622	0.609	0.887	0.901	0.632	0.695	1.030	1.047
Mean	34.1	41.4	1.47	45.4	Ave. error	0.089		0.052		0.039		0.016		0.027		0.050		0.018

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (March 7, 1973)

Environmental Conditions					Test Number*															
					23		25		24		32		35		34		29		33		6	
	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					2.030	2.030	1.924	1.924	1.934	1.934	1.848	1.848	1.917	1.917	1.892	1.892	1.894	1.894	1.949	1.949	1.940	1.940
	25.0	73.01	0.25																			
					1.983	1.936	1.884	1.825	1.882	1.792	1.802	1.704	1.880	1.862	1.863	1.842	1.854	1.834	1.912	1.903	1.906	1.883
	26.0	61.61	0.61																			
					1.882	1.822	1.784	1.707	1.774	1.624	1.684	1.533	1.785	1.769	1.768	1.757	1.756	1.733	1.812	1.825	1.799	1.787
	27.0	55.91	1.38																			
					1.698	1.681	1.615	1.561	1.578	1.423	1.501	1.330	1.638	1.626	1.638	1.627	1.603	1.580	1.669	1.705	1.652	1.640
4	30.5	51.84	1.33																			
					1.494	1.538	1.424	1.414	1.364	1.226	1.312	1.134	1.480	1.470	1.499	1.483	1.450	1.413	1.518	1.571	1.500	1.480
	32.5	46.96	1.02																			
					1.358	1.393	1.275	1.266	1.186	1.037	1.147	0.948	1.359	1.299	1.386	1.327	1.323	1.232	1.396	1.424	1.378	1.304
an	28.6	57.9	0.92	Ave. error	0.047		0.049		0.138		0.162		0.029		0.029		0.016		0.032		0.036	

Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (March 8, 1973)**

Hour	Environmental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 23 $\bar{M}_{exp.}$ d.b.	23 $\bar{M}_{cal.}$ d.b.	25 $\bar{M}_{exp.}$ d.b.	25 $\bar{M}_{cal.}$ d.b.	24 $\bar{M}_{exp.}$ d.b.	24 $\bar{M}_{cal.}$ d.b.	32 $\bar{M}_{exp.}$ d.b.	32 $\bar{M}_{cal.}$ d.b.	35 $\bar{M}_{exp.}$ d.b.	35 $\bar{M}_{cal.}$ d.b.	34 $\bar{M}_{exp.}$ d.b.	34 $\bar{M}_{cal.}$ d.b.	29 $\bar{M}_{exp.}$ d.b.	29 $\bar{M}_{cal.}$ d.b.	33 $\bar{M}_{exp.}$ d.b.	33 $\bar{M}_{cal.}$ d.b.	6 $\bar{M}_{exp.}$ d.b.	6 $\bar{M}_{cal.}$ d.b.
					1.041	1.041	1.023	1.023	0.890	0.890	0.832	0.832	1.131	1.131	1 160	1.160	1.064	1.064	1.148	1.148	1.118	1.118
1	25.0	59.8	0.36																			
					0.977	0.984	0.963	0.962	0.820	0.814	0.764	0.758	1.076	1.081	1.095	1.114	1.002	1.013	1.098	1.106	1.061	1.068
2	29.0	58.4	0.72																			
					0.884	0.907	0.869	0.881	0.723	0.716	0.675	0.662	0.966	0.993	0.986	1.031	0.886	0.922	0.994	1.031	0.946	0.978
3	27.0	68.1	1.54																			
					0.798	0.842	0.784	0.812	0.635	0.638	0.599	0.587	0.888	0.924	0.906	0.966	0.815	0.852	0.924	0.971	0.875	0.909
4	28.0	64.1	1.95																			
					0.712	0.772	0.692	0.740	0.542	0.560	0.516	0.513	0.800	0.845	0.815	0.890	0.721	0.773	0.832	0.902	0.781	0.829
5	29.5	55.1	1.64																			
					0.636	0.701	0.619	0.666	0.467	0.483	0.453	0.440	0.701	0.755	0.720	0.804	0.624	0.684	0.747	0.823	0.683	0.739
6	31.5	47.8	1.38																			
					0.558	0.627	0.545	0.591	0.396	0.409	0.382	0.370	0.597	0.658	0.624	0.709	0.522	0.588	0.639	0.734	0.580	0.641
7	33.0	43.7	1.33																			
					0.482	0.554	0.477	0.517	0.329	0.341	0.320	0.308	0.507	0.560	0.544	0.612	0.446	0.494	0.557	0.642	0.496	0.544
8	33.5	43.7	1.23																			
					0.424	0.490	0.414	0.453	0.272	0.287	0.283	0.258	0.437	0.476	0.481	0.527	0.380	0.415	0.502	0.561	0.431	0.460
9	33.0	43.7	2.88																			
					0.395	0.428	0.384	0.392	0.267	0.240	0.267	0.216	0.404	0.393	0.445	0.447	0.351	0.344	0.462	0.483	0.393	0.385
Mean	29.9	54.9	1.45	Ave. error		0.053		0.034		0.014		0.020		0.046		0.060		0.043		0.061		0.040

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on March 7.

Experimental and Calculated Average Moisture Content Values (March 10, 1973)

Environmental Conditions				Test Number*																	
				27		21		31		22		99		23		30		2		31	
T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
				2.003	2.003	2.139	2.139	1.738	1.738	1.877	1.877	2.076	2.076	2.082	2.082	1.884	1.884	2.410	2.410	2.230	2.230
30.0	53.5	3.65	45.0																		
				1.568	1.599	1.724	1.796	1.361	1.471	1.503	1.334	1.868	1.878	1.866	1.835	1.672	1.700	2.133	2.170	1.991	1.940
31.0	50.2	3.80	45.9																		
				1.135	1.238	1.339	1.475	1.044	1.223	1.078	0.903	1.640	1.672	1.638	1.583	1.478	1.510	1.878	1.917	1.752	1.645
29.0	53.5	4.01	14.3																		
				0.844	0.963	1.082	1.212	0.852	1.022	0.785	0.623	1.493	1.496	1.508	1.373	1.345	1.350	1.717	1.697	1.605	1.400
26.5	58.4	3.24	3.6																		
				0.693	0.780	0.933	1.025	0.738	0.379	0.622	0.465	1.386	1.368	1.403	1.224	1.260	1.235	1.600	1.537	1.512	1.228
ean 29.1	53.9	3.67	27.2	Ave. error	0.091		0.110		0.152		0.166		0.018		0.116		0.025		0.042		0.184

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (March 11, 1973)**

	Environmental Conditions				Test Number*													
					27		21		31		22		99		23		30		2		31	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.540	0.540	0.734	0.734	0.589	0.589	0.473	0.473	1.161	1.161	1.198	1.198	1.067	1.067	1.341	1.341	1.294	1.294
1	25.0	79.5	0.72	23.9																		
					0.504	0.495	0.690	0.679	0.553	0.551	0.441	0.420	1.111	1.127	1.155	1.155	1.027	1.036	1.294	1.298	1.250	1.242
2	27.5	63.2	1.08	40.1																		
					0.441	0.429	0.622	0.601	0.496	0.496	0.385	0.345	1.037	1.059	1.084	1.068	0.964	0.973	1.213	1.210	1.171	1.137
3	28.0	58.4	0.56	26.4																		
					0.375	0.373	0.558	0.532	0.385	0.446	0.342	0.287	0.977	0.990	1.018	0.982	0.909	0.911	1.140	1.124	1.113	1.035
Mean	26.8	67.0	0.78	30.1	Ave. error	0.008		0.020		0.035		0.041		0.017		0.022		0.007		0.010		0.049

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on March 10, 1973.

Experimental and Calculated Average Moisture Content Values (March 14, 1973)

Hour	Environmental Conditions T °C	RH %	u m/sec	R_t cal/cm²·hr	Test Number*													
					35		36		33		31		21		34		23		32	
					$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.987	1.987	1.541	1.541	1.960	1.960	1.838	1.838	1.613	1.613	1.791	1.791	1.899	1.899	2.065	2.065
1	32.0	48.6	0.77	66.3																
					1.613	1.739	1.277	1.274	1.783	1.774	1.643	1.640	1.351	1.413	1.600	1.578	1.729	1.755	1.866	1.920
2	35.0	45.3	1.90	62.1																
					1.634	1.574	1.093	0.968	1.695	1.550	1.435	1.407	1.093	1.095	1.330	1.332	1.559	1.566	1.620	1.734
3	35.0	46.1	2.82	48.1																
					1.379	1.349	0.765	0.744	1.365	1.327	1.103	1.181	0.827	0.814	1.076	1.098	1.365	1.373	1.375	1.530
4	33.6	46.1	3.65	43.3																
					1.098	1.139	0.535	0.584	1.062	1.120	0.918	0.977	0.643	0.711	0.869	0.891	1.136	1.191	1.171	1.324
5	32.5	43.2	2.83	44.3																
					0.932	0.974	0.423	0.428	0.880	0.958	0.777	0.820	0.532	0.617	0.701	0.736	1.058	1.045	1.022	1.166
Mean	33.1	46.9	2.40	47.6	Average error	0.042		0.017		0.080		0.036		0.129		0.031		0.013		0.127

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (March 15, 1973)**

Hour	Environmental Conditions				Test Number*													
					35		36		33		31		21		34		23		32	
	t °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
1	26.5	64.9	0.77	39.0	0.783	0.783	0.372	0.372	0.757	0.757	0.661	0.661	0.451	0.451	0.665	0.665	0.967	0.967	0.910	0.910
2	28.0	58.4	0.66	49.1	0.725	0.720	0.312	0.331	0.595	0.607	0.602	0.604	0.395	0.414	0.542	0.560	0.907	0.917	0.847	0.862
3	30.0	49.4	0.87	68.1	0.676	0.655	0.274	0.291	0.638	0.634	0.542	0.545	0.347	0.374	0.485	0.493	0.831	0.856	0.766	0.805
4	32.0	48.6	1.02	73.5	0.600	0.582	0.220	0.249	0.561	0.563	0.482	0.480	0.291	0.331	0.420	0.430	0.733	0.773	0.656	0.731
5	35.5	42.9	1.18	74.3	0.527	0.511	0.187	0.212	0.482	0.495	0.421	0.418	0.246	0.290	0.363	0.371	0.621	0.696	0.544	0.654
6	34.0	42.5	0.77	27.2	0.441	0.436	0.152	0.177	0.394	0.423	0.347	0.354	0.207	0.248	0.306	0.311	0.497	0.600	0.436	0.564
7	32.0	51.3	4.57	26.0	0.396	0.378	0.139	0.154	0.352	0.366	0.292	0.305	0.183	0.217	0.276	0.266	0.446	0.524	0.388	0.492
8	27.5	57.5	3.18	21.0	0.333	0.325	0.130	0.138	0.298	0.315	0.276	0.262	0.170	0.191	0.246	0.229	0.378	0.455	0.336	0.423
9	28.5	56.7	2.72	14.4	0.312	0.293	0.137	0.133	0.275	0.285	0.251	0.238	0.179	0.178	0.230	0.209	0.349	0.415	0.300	0.392
					0.282	0.266	0.137	0.128	0.254	0.260	0.230	0.217	0.161	0.167	0.216	0.192	0.324	0.380	0.290	0.359
Mean	30.4	52.5	1.75	43.2	Ave. error	0.015		0.018		0.013		0.010		0.029		0.013		0.065		0.035

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on March 14.

Experimental and Calculated Average Moisture Content Values (March 21, 1973)

Hour	Environmental Conditions T °C	RH %	u m/sec	R_{cal} cal/cm²hr	Test Number* 33 $\bar{M}_{exp.}$ d.b.	33 $\bar{M}_{cal.}$ d.b.	34 $\bar{M}_{exp.}$ d.b.	34 $\bar{M}_{cal.}$ d.b.	31 $\bar{M}_{exp.}$ d.b.	31 $\bar{M}_{cal.}$ d.b.	27 $\bar{M}_{exp.}$ d.b.	27 $\bar{M}_{cal.}$ d.b.	36 $\bar{M}_{exp.}$ d.b.	36 $\bar{M}_{cal.}$ d.b.	32 $\bar{M}_{exp.}$ d.b.	32 $\bar{M}_{cal.}$ d.b.	30 $\bar{M}_{exp.}$ d.b.	30 $\bar{M}_{cal.}$ d.b.	29 $\bar{M}_{exp.}$ d.b.	29 $\bar{M}_{cal.}$ d.b.	35 $\bar{M}_{exp.}$ d.b.	35 $\bar{M}_{cal.}$ d.b.
					2.080	2.080	1.898	1.898	1.925	1.925	2.270	2.270	1.918	1.918	2.062	2.062	2.007	2.007	1.774	1.774	1.623	1.620
1	32.5	40.4	1.49	68.4																		
					1.828	1.773	1.662	1.536	1.683	1.660	1.952	1.967	1.648	1.660	1.858	1.811	1.626	1.516	1.601	1.612	1.636	1.657
2	33.5	39.6	1.44	55.5																		
					1.583	1.497	1.417	1.207	1.444	1.407	1.635	1.671	1.441	1.414	1.650	1.567	1.635	1.624	1.421	1.442	1.498	1.466
3	34.0	38.0	4.98	44.9																		
					1.332	1.157	1.192	0.844	1.328	1.099	1.372	1.293	1.216	1.112	1.445	1.257	1.492	1.365	1.284	1.277	1.321	1.316
4	31.0	39.6	3.44	42.0																		
					1.061	0.911	0.815	0.609	0.933	0.875	1.064	1.017	0.896	0.891	1.099	1.024	1.289	1.160	1.046	1.124	1.134	1.162
5	32.0	43.7	1.18	22.7																		
					0.869	0.763	0.601	0.481	0.752	0.739	0.883	0.849	0.733	0.756	0.899	0.879	1.152	1.063	0.945	1.007	0.906	1.042
6	31.0	47.8	1.49	5.1																		
					0.746	0.644	0.500	0.389	0.643	0.630	0.749	0.714	0.631	0.667	0.775	0.769	1.075	0.967	0.872	0.904	0.925	0.945
Mean	32.8	41.4	2.34	39.8	Ave error	0.132		0.234		0.060		0.045		0.044		0.047		0.107		0.033		0.037

* Identifications of the test numbers are given in pp. 207 to 213

Experimental and Calculated Average Moisture Content Values (March 22, 1973)**

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 33 $\bar{M}_{exp.}$ d.b.	33 $\bar{M}_{cal.}$ d.b.	34 $\bar{M}_{exp.}$ d.b.	34 $\bar{M}_{cal.}$ d.b.	31 $\bar{M}_{exp.}$ d.b.	31 $\bar{M}_{cal.}$ d.b.	30 $\bar{M}_{exp.}$ d.b.	30 $\bar{M}_{cal.}$ d.b.	29 $\bar{M}_{exp.}$ d.b.	29 $\bar{M}_{cal.}$ d.b.	35 $\bar{M}_{exp.}$ d.b.	35 $\bar{M}_{cal.}$ d.b.
					0.409	0.409	0.241	0.241	0.365	0.365	0.635	0.635	0.555	0.555	0.688	0.688
1	27.0	58.4	0.72	30.2												
					0.369	0.368	0.213	0.218	0.326	0.332	0.590	0.595	0.511	0.522	0.644	0.647
2	28.5	55.9	1.13	61.3												
					0.324	0.328	0.187	0.196	0.288	0.299	0.514	0.549	0.443	0.487	0.570	0.602
3	30.0	49.8	0.77	34.8												
					0.285	0.290	0.168	0.175	0.253	0.267	0.454	0.500	0.390	0.445	0.515	0.549
4	32.5	47.0	1.13	58.9												
					0.253	0.251	0.156	0.155	0.222	0.235	0.380	0.444	0.328	0.398	0.445	0.490
5	35.0	42.1	1.18	50.8												
					0.220	0.214	0.143	0.136	0.201	0.203	0.322	0.384	0.277	0.347	0.384	0.425
6	34.5	42.5	1.69	58.6												
					0.191	0.185	0.129	0.123	0.171	0.178	0.268	0.334	0.235	0.305	0.330	0.371
7	33.0	42.1	3.39	29.4												
					0.173	0.162	0.127	0.114	0.163	0.157	0.239	0.289	0.204	0.273	0.289	0.329
8	31.5	42.9	3.24	23.6												
					0.161	0.146	0.121	0.108	0.148	0.143	0.216	0.256	0.183	0.248	0.258	0.297
9	31.5	47.0	4.11	22.8												
					0.155	0.135	0.117	0.106	0.150	0.133	0.202	0.229	0.172	0.229	0.236	0.272
Mean	31.5	47.5	1.93	41.16	Ave. error	0.009		0.008		0.009		0.047		0.059		0.036

* Identifications of the test numbers are given in pages 220-226
** Continuation of experiment on March 21.

Experimental and Calculated Average Moisture Content Values (March 22, 1973)**

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 33 $\bar{M}_{exp.}$ d.b.	33 $\bar{M}_{cal.}$ d.b.	34 $\bar{M}_{exp.}$ d.b.	34 $\bar{M}_{cal.}$ d.b.	31 $\bar{M}_{exp.}$ d.b.	31 $\bar{M}_{cal.}$ d.b.	30 $\bar{M}_{exp.}$ d.b.	30 $\bar{M}_{cal.}$ d.b.	29 $\bar{M}_{exp.}$ d.b.	29 $\bar{M}_{cal.}$ d.b.	35 $\bar{M}_{exp.}$ d.b.	35 $\bar{M}_{cal.}$ d.b.
					0.409	0.409	0.241	0.241	0.365	0.365	0.635	0.635	0.555	0.555	0.688	0.688
1	27.0	58.4	0.72	30.2												
					0.369	0.368	0.213	0.218	0.326	0.332	0.590	0.595	0.511	0.522	0.644	0.647
2	28.5	55.9	1.13	61.3												
					0.324	0.328	0.187	0.196	0.288	0.299	0.514	0.549	0.443	0.487	0.570	0.602
3	30.0	49.8	0.77	34.8												
					0.285	0.290	0.168	0.175	0.253	0.267	0.454	0.500	0.390	0.445	0.515	0.549
4	32.5	47.0	1.13	58.9												
					0.253	0.251	0.156	0.155	0.222	0.235	0.380	0.444	0.328	0.398	0.445	0.490
5	35.0	42.1	1.18	50.8												
					0.220	0.214	0.143	0.136	0.201	0.203	0.322	0.384	0.277	0.347	0.384	0.425
6	34.5	42.5	1.69	58.6												
					0.191	0.185	0.129	0.123	0.171	0.178	0.268	0.334	0.235	0.305	0.330	0.371
7	33.0	42.1	3.39	29.4												
					0.173	0.162	0.127	0.114	0.163	0.157	0.239	0.289	0.204	0.273	0.289	0.329
8	31.5	42.9	3.24	23.6												
					0.161	0.146	0.121	0.108	0.148	0.143	0.216	0.256	0.183	0.248	0.258	0.297
9	31.5	47.0	4.11	22.8												
					0.155	0.135	0.117	0.106	0.150	0.133	0.202	0.229	0.172	0.229	0.236	0.272
Mean	31.5	47.5	1.93	41.16	Ave. error	0.009		0.008		0.009		0.047		0.059		0.036

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on March 21.

Experimental and Calculated Average Moisture Content Values (March 24, 1973)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 34 $\bar{M}_{exp.}$ d.b.	34 $\bar{M}_{cal.}$ d.b.	31 $\bar{M}_{exp.}$ d.b.	31 $\bar{M}_{cal.}$ d.b.	36 $\bar{M}_{exp.}$ d.b.	36 $\bar{M}_{cal.}$ d.b.	27 $\bar{M}_{exp.}$ d.b.	27 $\bar{M}_{cal.}$ d.b.	32 $\bar{M}_{exp.}$ d.b.	32 $\bar{M}_{cal.}$ d.b.	33 $\bar{M}_{exp.}$ d.b.	33 $\bar{M}_{cal.}$ d.b.
					2.159	2.159	2.081	2.081	1.989	1.989	2.092	2.092	2.042	2.042	2.072	2.072
1	30.0	58.4	1.49	22.6	2.047	1.950	1.963	1.800	1.879	1.795	1.987	1.905	1.954	1.862	1.989	1.815
2	34.5	55.1	1.44	49.7	1.884	1.727	1.794	1.505	1.719	1.587	1.841	1.703	1.815	1.668	1.843	1.543
3	32.5	54.3	2.93	47.3	1.627	1.489	1.457	1.212	1.437	1.369	1.570	1.487	1.559	1.461	1.580	1.269
4	31.0	52.7	4.01	48.4	1.319	1.257	1.090	0.950	1.134	1.158	1.268	1.275	1.264	1.257	1.224	1.018
5	29.5	58.4	3.49	24.0	1.103	1.081	0.829	0.768	0.932	0.999	1.061	1.111	1.046	1.100	0.976	0.838
6	29.0	64.1	2.72	35.5	0.969	0.950	0.686	0.642	0.818	0.881	0.937	0.988	0.910	0.980	0.827	0.711
7	26.5	68.1	2.93	----	0.836	0.843	0.572	0.548	0.709	0.785	0.823	0.885	0.801	0.881	0.701	0.614
Mean	30.4	58.7	2.71	37.9	Ave. error	0.090		0.167		0.079		0.077		0.087		0.206

* Identifications of the test numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (March 25, 1973)**

	Environmental Conditions				Test Number*													
					34		31		36		27		32		33		23	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.793	0.793	0.547	0.547	0.673	0.673	0.766	0.766	0.756	0.756	----	----	1.204	1.204
1	25.0	68.9	0.41	15.1														
					0.747	0.734	0.511	0.494	0.636	0.625	0.725	0.714	0.715	0.706	----	----	1.169	1.168
2	26.0	64.1	1.08	7.8														
					0.667	0.667	0.434	0.437	0.555	0.571	0.643	0.655	0.643	0.649	0.545	0.532	1.037	1.118
3	28.5	55.1	1.18	52.7														
					0.583	0.593	0.361	0.376	0.480	0.510	0.557	0.588	0.561	0.584	0.464	0.461	0.990	1.051
4	30.5	51.0	0.97	59.0														
					0.509	0.521	0.304	0.319	0.418	0.451	0.483	0.523	0.492	0.521	0.393	0.393	0.903	0.976
5	32.5	42.1	0.92	72.1														
					0.442	0.446	0.254	0.264	0.355	0.389	0.420	0.454	0.427	0.454	0.332	0.326	0.805	0.885
Mean	28.5	56.2	0.91	41.54	Ave. error	0.009		0.012		0.026		0.026		0.021		0.011		0.057

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment of March 24.

Experimental and Calculated Average Moisture Content Values (March 28, 1973)

	Environmental Conditions				Test Number*													
					31		33		36		34		27		24		32		22		23	
our	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					2.009	2.009	1.915	1.915	1.840	1.840	2.019	2.019	2.189	2.189	2.061	2.061	2.297	2.297	1.977	1.977	1.987	1.987
	29.0	51.0	1.23	51.6																		
					1.800	1.791	1.740	1.703	1.660	1.632	1.862	1.819	1.991	1.980	1.796	1.822	2.082	2.137	1.854	1.874	1.834	1.857
	34.0	43.7	2.21	46.4																		
					1.468	1.512	1.451	1.433	1.376	1.370	1.582	1.562	1.664	1.709	1.399	1.519	1.806	1.879	1.690	1.711	1.661	1.652
	34.0	44.5	3.54	54.0																		
					1.103	1.233	1.106	1.166	1.043	1.112	1.217	1.301	1.264	1.428	1.032	1.218	1.500	1.599	1.449	1.534	1.429	1.434
4	33.0	44.5	3.85	49.0																		
					0.850	0.997	0.872	0.942	0.832	0.897	0.922	1.075	0.946	1.181	0.774	0.967	1.235	1.346	1.281	1.371	1.226	1.239
	31.5	47.8	4.32	37.9																		
					0.682	0.808	0.687	0.764	0.658	0.728	0.724	0.889	0.760	0.977	----	----	1.077	1.134	1.148	1.228	1.095	1.073
	29.5	53.5	2.77	35.3																		
					0.574	0.687	0.578	0.650	0.551	0.619	0.613	0.767	0.645	0.841	0.520	0.647	0.974	0.998	1.076	1.131	1.011	0.965
ean	31.8	47.5	2.99	35.0	Ave. error	0.107		0.059		0.056		0.117		0.169		0.147		0.075		0.065		0.023

Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (March 29, 1973)**

Hour	Environmental Conditions				Test Load*													
					31		33		36		34		27		24		22		23	
	T	RH	u	R_i	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.	$\bar{M}$ exp.	$\bar{M}$ cal.
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					0.364	0.364	0.315	0.315	0.366	0.366	0.329	0.329	0.373	0.373	0.277	0.277	0.774	0.774	0.748	0.748
1	26.5	77.9	0.51	16.3	0.337	0.346	0.297	0.302	0.346	0.348	0.305	0.307	0.350	0.355	0.265	0.266	0.747	0.746	0.722	0.726
2	28.0	66.5	0.51	17.8	0.316	0.322	0.278	0.282	0.324	0.323	0.292	0.289	0.329	0.333	0.250	0.250	0.723	0.723	0.691	0.692
3	27.5	59.0	0.41	33.6	0.283	0.286	0.251	0.261	0.294	0.297	0.266	0.269	0.297	0.307	0.218	0 231	0.680	0.693	0.645	0.661
4	29.0	51.8	0.77	35.3	0.255	0.266	0.221	0.237	0.261	0.268	0.233	0.246	0.264	0 278	0.202	0.210	0.634	0.659	0.614	0.597
5	30 5	53.5	0.61	34.1	0.233	0.241	0.199	0.217	0.230	0.243	0.213	0.226	0.235	0.253	----	----	0.593	0.604	0.560	0.546
6	31.5	43.7	0.66	35.6	0.207	0.214	0.181	0.194	0.216	0.215	0.194	0.204	0.214	0.226	0.163	0.173	0 542	0.551	0.490	0.497
7	33.0	43.7	0.77	43.9	0.185	0.191	0.162	0.175	0.195	0.192	0.174	0.181	0.187	0.202	0.143	0.154	0.463	0.469	0.447	0.449
8	33.0	45.3	1.13	24.9	0 173	0.172	0 151	0.159	----	----	0.163	0.168	0.173	0.188	0.143	0.144	0.451	0 452	0.434	0 [illegible]
9	31.0	49.4	2.62	19.0	0.153	0.154	0.138	0.148	0.169	0.169	0.160	0 166	0.172	0 [illegible]	0.143	0.144	0.451	0.452	0.434	0.430
					Ave.															
Ave.	29.7	54.7	0.71	29.5	Error	0.008	0.011		0.004		0.009		0.015		0.005		0.012		0.011	

* Test loads are given in pounds

** Continuation of experiment on March 29.

207 to 213

Experimental and Calculated Average Moisture Content Values (March 31, 1973)

Environmental Conditions					Test Number*													
					36		33		34		31		27		24		32		22	
Hour	T °C	RH %	u m/sec	R_t cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.979	1.979	1.984	1.984	2.231	2.231	1.917	1.917	2.113	2.113	2.149	2.149	1.965	1.965	2.202	2.202
1	33.5	47.8	1.54	66.5																
					1.813	1.819	1.754	1.720	2.409	1.305	1.733	1.734	1.918	1.863	1.908	1.777	1.748	1.770	1.959	1.978
2	34.0	45.3	1.28	42.4																
					1.638	1.643	1.518	1.473	1.869	1.501	1.535	1.538	1.709	1.626	1.654	1.437	1.592	1.577	1.777	1.753
3	32.5	47.0	2.26	30.9																
					1.379	1.458	1.165	1.230	1.501	1.259	1.227	1.321	1.357	1.396	1.252	1.131	1.414	1.390	1.571	1.581
4	31.5	50.2	3.08	17.1																
					1.144	1.276	0.951	1.033	1.206	1.000	0.946	1.109	1.040	1.161	0.890	0.876	1.267	1.219	1.391	1.338
5	31.0	51.9	2.72	15.0																
					0.879	1.078	0.692	0.883	0.921	0.802	----	----	0.809	1.011	0.666	0.689	1.151	1.979	1.237	1.155
6	29.0	55.7	2.77	5.8																
					0.719	0.943	0.580	0.741	0.776	0.653	0.603	0.859	0.856	0.824	0.525	0.587	1.069	0.966	1.123	1.023
Mean	31.9	49.8	2.28	20.3	Ave. error	0.139		0.128		0.209		0.135		0.141		0.115		0.057		0.035

* Identification of the test numbers are given in pages **207 to 213**

Experimental and Calculated Average Moisture Content Values (April 1, 1973)**

Hour	Environmental Conditions T °C	RH %	v m/sec	R_s cal/cm²hr	Test Number* 36 $\bar{M}$ exp. d.b.	36 $\bar{M}$ cal. d.b.	33 $\bar{M}$ exp. d.b.	33 $\bar{M}$ cal. d.b.	34 $\bar{M}$ exp. d.b.	34 $\bar{M}$ cal. d.b.	31 $\bar{M}$ exp. d.b.	31 $\bar{M}$ cal. d.b.	27 $\bar{M}$ exp. d.b.	27 $\bar{M}$ cal. d.b.	24 $\bar{M}$ exp. d.b.	24 $\bar{M}$ cal. d.b.	32 $\bar{M}$ exp. d.b.	32 $\bar{M}$ cal. d.b.	22 $\bar{M}$ exp. d.b.	22 $\bar{M}$ cal. d.b.
					0.567	0.567	0.402	0.402	0.558	0.558	0.479	0.479	0.482	0.482	0.381	0.381	0.939	0.939	0.957	0.957
1	22.5	83.6	0.56	17.9																
					0.547	0.555	0.385	0.386	0.541	0.522	0.457	0.469	0.467	0.481	0.365	0.361	0.915	0.919	0.934	0.934
2	25.0	78.7	1.28	43.2																
					0.503	0.531	0.344	0.363	0.496	0.477	0.415	0.447	0.415	0.433	0.321	0.334	----	----	0.852	0.892
3	28.0	62.4	0.97	62.5																
					0.444	0.486	0.290	0.331	0.438	0.418	0.362	0.406	0.362	0.394	0.268	0.295	0.750	0.822	0.746	0.823
4	30.0	54.3	0.97	68.7																
					0.383	0.430	0.244	0.295	----	----	0.308	0.357	0.299	0.352	0.216	0.255	0.641	0.746	0.613	0.738
5	32.0	47.0	1.08	76.2																
					0.322	0.367	0.200	0.253	0.307	0.298	0.257	0.302	0.248	0.303	0.132	0.216	0.527	0.657	0.431	0.639
Mean	27.5	65.2	0.97	63.8	Ave. error	0.036		0.039		0.017		0.039		0.039		0.026		0.082		0.098

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on March 31.

Experimental and Calculated Average Moisture Content Values (April 4, 1973)

Hour	Environmental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 34 $\bar{M}$ exp. d.b.	34 $\bar{M}$ cal. d.b.	33 $\bar{M}$ exp. d.b.	33 $\bar{M}$ cal. d.b.	27 $\bar{M}$ exp. d.b.	27 $\bar{M}$ cal. d.b.	31 $\bar{M}$ exp. d.b.	31 $\bar{M}$ cal. d.b.	24 $\bar{M}$ exp. d.b.	24 $\bar{M}$ cal. d.b.	36 $\bar{M}$ exp. d.b.	36 $\bar{M}$ cal. d.b.	32 $\bar{M}$ exp. d.b.	32 $\bar{M}$ cal. d.b.	22 $\bar{M}$ exp. d.b.	22 $\bar{M}$ cal. d.b.
					1.931	1.931	1.790	1.790	1.969	1.969	1.757	1.757	1.773	1.773	1.843	1.843	1.819	1.819	1.836	1.836
1	34.0	40.4	1.64	58.2																
					1.755	1.710	1.539	1.519	1.818	1.803	1.520	1.583	1.474	1.526	1.610	1.623	1.650	1.652	1.808	1.731
2	34.0	38.9	1.69	32.6																
					1.584	1.528	1.306	1.268	1.674	1.618	1.308	1.416	1.194	1.264	1.376	1.385	1.512	1.487	1.615	1.529
3	33.0	42.1	3.03	30.7																
					1.319	1.290	1.030	1.037	1.433	1.402	1.077	1.250	0.838	0.994	1.056	1.101	1.372	1.326	1.464	1.332
4	33.2	39.6	2.62	28.7																
					1.115	1.068	0.837	0.842	1.263	1.297	0.915	1.101	0.705	0.771	0.871	0.903	1.259	1.176	1.337	1.152
5	30.0	43.7	2.00	6.3																
					0.990	0.915	0.712	0.710	1.125	1.051	0.798	0.990	0.580	0.628	0.731	0.754	1.176	1.069	1.240	1.027
Mean	32.8	40.9	2.20	31.3	Ave. error	0.048		0.020		0.051		0.152		0.072		0.034		0.064		0.148

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (April 5, 1973)**

	Environmental Conditions				Test Number*													
					34		33		27		31		24		36		32		22	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
1	23.5	78.7	0.66	12 4	0.978	0.978	0.665	0.665	1.113	1.113	0.754	0.754	0.675	0.675	0.691	0.691	1.164	1.164	1.216	1.216
2	24.0	77.9	0.56	20 3	0.960	0.947	0.640	0.622	1.091	1.084	0.732	0.722	0.642	0.648	0.666	0.666	1.141	1.138	1.197	1.183
3	26.0	60.8	0.66	45.0	0.929	0.917	0.602	0.582	1.058	1.055	0.703	0.690	0.595	0.622	0.633	0.641	1.113	1.112	1.163	1.151
4	27.0	58.4	1.74	32.2	0.878	0.853	0.551	0.527	1.005	0.993	0.656	0.647	0.539	0.566	0.579	0.588	1.051	1.062	1.101	1.090
5	28.0	55.9	2.05	37.1	0.814	0.768	0.493	0.467	0.910	0.907	0.585	0.597	0.475	0.497	0.525	0.522	0.988	0.997	1.039	1.019
6	29.0	55.1	2.26	44.1	0.733	0.678	0.424	0.410	0.849	0.814	0.533	0.547	0.416	0.427	0.463	0.455	0.913	0.927	0.958	0.925
7	29.0	50.2	2.52	45.0	0.667	0.591	0.367	0.359	0.772	0.721	0.479	0.499	0.368	0.364	0.410	0.392	0.839	0.856	0.880	0.840
8	29.0	50.2	2.52	31.3	0.585	0.505	0.325	0.312	0.671	0.628	0.425	0.452	0.323	0.306	0.359	0.334	0.760	0.782	0.798	0.753
9	28.0	50.2	3.24	13.0	0.507	0.433	0.288	0.274	0.574	0.546	0.384	0.411	0.288	0.261	0.324	0.286	0.689	0.714	0.717	0.675
					0.450	0.370	0.265	0.241	0.497	0.472	0.355	0.373	0.267	0.224	0.296	0.247	0.629	0.650	0.655	0.603
Mean	27.1	59.7	1.80	31.2	Ave. error	0.057	0.018		0.028		0.018		0.023		0.023		0.015		0.033	

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on April 4.

Experimental and Calculated Average Moisture Content Values (April 7, 1973)

	Environmental Conditions				Test Number*															
					24		31		33		36		27		34		29		7		32	
our	T °C	RH %	u m/sec	R_i cal/cm^{2}hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.813	1.813	1.890	1.890	1.954	1.954	1.975	1.975	1.867	1.867	2.019	2.019	1.906	1.906	2.078	2.078	1.973	1.973
	25.5	70.6	0.61	46.6																		
					1.737	1.672	1.819	1.796	1.881	1.908	1.920	1.934	1.757	1.812	1.905	1.984	1.839	1.856	2.008	2.031	1.905	1.912
2	28.0	62.4	2.52	44.3																		
					1.570	1.467	1.645	1.656	1.693	1.749	1.762	1.790	1 538	1.638	1.834	1.856	1.729	1.750	1.896	1.959	1.800	1.783
3	27.5	61.6	2.62	45.5																		
					1.405	1.282	1.491	1.523	1.505	1.	1.611	1.643	1.316	1.463	1.704	1.724	1.620	1.646	1.782	1.888	1.684	1.657
4	28.0	57.5	2.36	14.1																		
					1.236	1.114	1.346	1.396	1.330	1.426	1.469	1.496	1.127	1.292	1.540	1.592	1.545	1.542	1.709	1.804	1.611	1.531
	26.5	63.2	1.69	5.4																		
					1.155	0 990	1.267	1.209	1.248	1.312	1.402	1.392	1.032	1.172	1.521	1.498	1.506	1.466	1.670	1.740	1.568	1.440
Mean	27.1	63.08	1.96	31.2	Ave. error	0.119		0.082		0 068		0.023		0.127		0.083		0.024		0.076		0.068

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (April 8, 1973)**

Environmental Conditions					Test Number*															
					24		31		33		36		27		34		29		7		32	
ur	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.981	0.981	1.068	1.068	1.075	1.075	1.215	1.215	0.887	0.887	1.353	1.353	1.351	1.351	1.504	1.504	1.420	1.420
	26.0	68.9	0.51	53.5																		
					0.927	0.899	1.015	1.009	1.013	1.018	1.162	1.162	0.808	0.821	1.306	1.304	1.297	1.307	1.415	1.404	1.366	1.366
	27.0	61.6	0.51	39.2																		
					0.808	0.811	0.957	0.946	0.942	0.944	1.095	1.090	0.727	0.760	1.234	1.239	1.258	1.251	1.360	1.367	1.295	1.297
	29.0	54.3	0.64	43.1																		
					0.791	0.715	0.808	0.874	0.856	0.846	1.023	0.994	0.646	0.698	1.183	1.189	1.164	1.176	1.309	1.297	1.227	1.207
4	31.0	50.2	0.72	49.0																		
					0.711	0.621	0.810	0.799	0.771	0.733	0.936	0.881	0.555	0.567	1.101	1.039	1.085	1.092	1.233	1.191	1.146	1.102
Mean	28.3	58.8	0.59	46.2	Ave. error	0.066		0.010		0.019		0.031		0.023		0.036		0.011		0.022		0.024

* Identifications of the test numbers are given in pages **207 to 213**

** Continuation of experiment on April 7.

Experimental and Calculated Average Moisture Content Values (April 11, 1973)

	Environmental Conditions				Test Number*													
					34		33		24		27		31		36		32		29		7	
Hour	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					1.890	1.890	1.911	1.911	1.884	1.884	1.944	1.944	1.951	1.951	1.916	1.916	1.913	1.913	1.978	1.978	2.005	2.005
1	27.5	54.3	1.44	46.1																		
					1.716	1.758	1.736	1.783	1.639	1.680	1.794	1.832	1.832	1.853	1.711	1.729	1.784	1.794	1.853	1.878	1.893	1.915
2	30.0	47.0	1.23	71.3																		
					1.549	1.619	1.550	1.635	1.494	1.471	1.636	1.696	1.694	1.734	1.479	1.612	1.625	1.653	1.708	1.759	1.740	1.790
3	30.0	45.3	1.23	70.4																		
					1.342	1.486	1.380	1.472	1.241	1.276	1.410	1.553	1.506	1.606	1.180	1.433	1.430	1.512	1.533	1.639	1.554	1.662
4	30.0	43.7	1.38	43.9																		
					1.162	1.353	1.042	1.296	1.017	1.095	1.174	1.396	1.295	1.466	0.954	1.243	1.299	1.372	1.410	1.517	1.442	1.533
5	29.0	41.1	0.56	7.4																		
					1.062	1.248	0.970	1.167	0.922	0.958	1.077	1.276	1.208	1.359	0.848	1.101	1.233	1.264	1.344	1.422	1.389	1.420
6	27.5	54.5	2.67	30.4																		
					0.947	1.134	0.822	1.013	0.788	0.823	0.932	1.129	1.063	1.223	0.703	0.940	1.153	1.150	1.273	1.319	1.330	1.338
7	25.0	62.2	2.77	2.1																		
					0.860	1.043	0.706	0.902	0.700	0.722	0.821	1.019	0.945	1.119	0.618	0.826	1.090	1.067	1.216	1.241	1.283	1.288
Mean	28.42	50.45	1.51	35.9	Ave. error	0.156		0.170		0.039		0.165		0.130		0.217		0.045		0.070		0.058

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (April 12, 1973)**

	Environmental Conditions				Test Number*															
					34		33		24		27		31		36		32		29		7	
our	T °C	RH %	u m/sec	R_i cal/cm²/hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.637	0.637	0.416	0.416	0.494	0.494	0.488	0.488	0.693	0.693	0.381	0.381	0.793	0.793	0.918	0.918	1.052	1.052
1	22.5	77.9	0.20	17.9																		
					0.612	0.613	0.389	0.405	0.465	0.468	0.460	0.475	0.671	0.678	0.358	0.371	0.768	0.776	0.892	0.901	1.029	1.032
2	26.0	60.0	0.65	46.5																		
					0.559	0.574	0.347	0.372	0.410	0.425	0.413	0.440	0.619	0.632	0.308	0.339	0.707	0.731	0.833	0.855	0.968	0.979
3	28.0	46.7	0.97	72.3																		
					0.493	0.523	0.293	0.326	0.349	0.374	0.358	0.388	0.554	0.564	0.262	0.294	0.628	0.667	0.753	0.795	0.887	0.901
4	30.0	41.3	1.13	77.0																		
					0.426	0.476	0.248	0.286	0.294	0.323	0.307	0.332	0.463	0.487	0.220	0.247	0.525	0.593	0.654	0.723	0.782	0.810
5	31.0	39.5	1.43	67.0																		
					0.[illegible]	0.[illegible]	0.[illegible]	0.231	0.246	0.276	0.254	0.280	0.402	0.414	0.185	0.206	0.475	0.521	0.574	0.649	0.[illegible]	0.[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]																		
					0.[illegible]	0.[illegible]	0.[illegible]	0.192	0.212	0.235	0.215	0.232	0.330	0.343	0.162	0.170	0.373	0.449	0.498	0.574	0.596	0.625
7	31.5	28.8	1.60	49.3																		
					0.[illegible]	0.[illegible]	0.152	0.165	0.182	0.204	0.181	0.198	0.265	0.290	0.147	0.147	0.319	0.392	0.438	0.510	0.526	0.561
	[illegible]	[illegible]	[illegible]	[illegible]																		
					0.288	0.380	0.143	0.158	0.174	0.186	0.158	0.180	0.224	0.[illegible]	0.[illegible]	0.[illegible]	0.279	0.[illegible]	0.402	0.468	0.461	0.513
[illegible]	28.6	49.1	1.39	47.5	Ave. error	0.043		0.002		0.021		0.021		0.017		0.[illegible]		0.013		0.059		0.[illegible]

*Identifications of the test numbers are given on pages 207 to 213

**Continuation of experiment on April 11.

Experimental and Calculated Average Moisture Content Values (April 14, 1973)

Environmental Conditions					Test Number*															
					24		33		36		34		31		27		32		7		29	
our	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.893	1.893	1.901	1.901	1.894	1.894	1.909	1.909	1.929	1.929	1.877	1.877	1.954	1.954	2.226	2.226	1.999	1.999
	32.5	38.8	0.82	63.1																		
					1.727	1.667	1.706	1.743	1.713	1.727	1.749	1.763	1.798	1.796	1.677	1.632	1.785	1.782	1.727	2.080	1.830	1.822
	33.0	38.0	1.02	61.4																		
					1.547	1.443	1.483	1.583	1.488	1.527	1.570	1.614	1.643	1.659	1.454	1.392	1.626	1.606	1.591	1.923	1.673	1.638
	34.0	34.7	0.87	55.4																		
					1.365	1.228	1.290	1.422	1.296	1.302	1.393	1.465	1.487	1.521	1.234	1.164	1.446	1.416	1.456	1.755	1.516	1.445
	33.5	38.0	3.03	27.1																		
					1.038	1.008	1.016	1.248	0.927	1.038	1.082	1.301	1.192	1.366	0.888	0.937	1.262	1.255	1.303	1.564	1.340	1.242
	30.5	46.1	3.89	10.6																		
					0.859	0.840	0.881	1.103	0.744	0.837	0.951	1.162	1.023	1.234	0.742	0.768	----	----	1.268	1.409	1.279	1.086
	27.0	51.0	3.45	1.7																		
					0.724	0.720	0.781	0.992	0.611	0.704	0.840	1.055	0.905	1.130	0.630	0.650	1.127	1.075	1.185	1.294	1.206	0.975
Mean	31.8	41.1	2.16	36.6	Ave. error	0.075		0.171		0.072		0.155		0.145		0.048		0.036		0.265		0.133

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values (April 15, 1973)**

Environmental Conditions					Test Number*															
					24		33		36		34		31		27		32		7		29	
ur	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.542	0.542	0.598	0.598	0.505	0.505	0.625	0.625	0.700	0.700	0.515	0.515	1.016	1.016	1.022	1.022	0.968	0.968
	22.5	67.3	0.87	23.3																		
					0.502	0.503	0.550	0.567	0.462	0.475	0.588	0.595	0.663	0.668	0.467	0.475	0.980	0.984	0.992	0.987	0.934	0.929
	25.5	61.6	0.36	35.9																		
					0.468	0.463	0.511	0.585	0.420	0.441	0.546	0.563	0.623	0.635	0.419	0.435	0.935	0.937	0.952	0.947	0.896	0.893
	27.5	50.2	0.61	61.8																		
					0.415	0.416	0.451	0.495	0.368	0.392	0.488	0.524	0.562	0.595	0.358	0.387	0.845	0.868	0.865	0.887	0.811	0.815
4	28.5	47.0	0.72	36.2																		
					0.366	0.378	0.400	0.455	0.319	0.342	0.434	0.485	0.503	0.553	0.308	0.342	0.774	0.796	0.788	0.823	0.744	0.744
	29.5	43.7	0.61	53.5																		
					0.330	0.328	0.367	0.416	0.285	0.295	0.388	0.446	0.456	0.512	0.267	0.301	0.698	0.719	0.732	0.757	0.683	0.672
Mean	26.7	54.0	0.63	42.1	Ave. error	0.003		0.040		0.019		0.039		0.037		0.026		0.017		0.022		0.008

* Identifications of the test numbers are given in pages 204 to 213

Experimental and Calculated Average Moisture Content Values (April 17, 1973)

Enviromental Conditions					Test Number*											
					27		34		36		24		33		31	
Hour	T	RH	u	R_i	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$	$\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.	d.b.
					1.747	1.747	1.708	1.708	1.708	1.708	1.741	1.741	1.857	1.857	1.809	1.809
1	23.0	81.2	0.72		1.704	1.677	1.664	1.634	1.651	1.628	1.693	1.704	1.832	1.827	1.773	1.776
2	22.0	90.9	0.82		1.682	1.619	1.643	1.572	1.625	1.562	1.680	1.680	1.821	1.808	1.766	1.754
3	21.5	92.6	0.87		1.679	1.564	1.637	1.515	1.621	1.500	1.672	1.658	1.815	1.788	1.760	1.733
4	22.0	90.9	0.77		1.676	1.511	1.633	1.459	1.615	1.440	1.664	1.636	1.811	1.770	1.754	1.713
5	21.5	84.4	0.56		1.659	1.456	1.615	1.401	1.587	1.379	1.639	1.612	1.795	1.752	1.740	1.692
6	21.5	84.4	0.15		1.648	1.408	1.598	1.352	1.564	1.327	1.621	1.605	1.787	1.749	1.726	1.687
7	21.0	86.0	0.00		1.638	1.366	1.580	1.308	1.551	1.280	1.599	1.606	1.779	1.753	1.722	1.690
8	21.0	86.0	0.36		1.623	1.321	1.558	1.261	1.513	1.231	1.585	1.594	1.765	1.744	1.699	1.680
9	21.0	87.7	0.82		1.607	1.274	1.543	1.212	1.494	1.180	1.570	1.566	1.757	1.721	1.678	1.654
10	20.0	90.9	0.66		1.590	1.234	1.525	1.171	1.477	1.137	1.541	1.550	1.750	1.708	1.670	1.639
11	20.0	92.6	1.23		1.582	1.191	1.515	1.128	1.466	1.092	1.533	1.516	1.741	1.678	1.668	1.607
12	20.0	92.6	0.66		1.573	1.156	1.502	1.092	1.453	1.055	1.522	1.502	1.734	1.667	1.654	1.595
Mean	21.2	88.3	0.63	Ave. error	0.270		0.270		0.260		0.016		0.039		0.037	

* Identification of the numbers are given in pages 220-226

Experimental and Calculated Average Moisture Content Values (April 17 night, 1973)**

Hour	Environmental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* 27 $\bar{M}$ exp. d.b.	27 $\bar{M}$ cal. d.b.	34 $\bar{M}$ exp. d.b.	34 $\bar{M}$ cal. d.b.	36 $\bar{M}$ exp. d.b.	36 $\bar{M}$ cal. d.b.	24 $\bar{M}$ exp. d.b.	24 $\bar{M}$ cal. d.b.	33 $\bar{M}$ exp. d.b.	33 $\bar{M}$ cal. d.b.	31 $\bar{M}$ exp. d.b.	31 $\bar{M}$ cal. d.b.	24 $\bar{M}$ exp. d.b.	24 $\bar{M}$ cal. d.b.	7 $\bar{M}$ exp. d.b.	7 $\bar{M}$ cal. d.b.
1	23.50	77.9	0.61	0.0	0.609	0.609	0.533	0.533	0.485	0.485	0.344	0.344	0.656	0.655	0.462	0.462	0.934	0.934	0.893	0.893
2	23.50	85.2	0.30	0.0	0.594	0.586	0.521	0.512	0.477	0.465	0.338	0.333	0.637	0.634	0.448	0.446	0.923	0.913	0.879	0.874
3	22.5	92.6	0.41	0.0	0.580	0.570	0.508	0.498	0.464	0.452	0.330	0.329	0.626	0.624	0.434	0.439	0.922	0.901	0.877	0.863
4	22.0	91.7	0.15	0.0	0.580	0.559	0.508	0.489	0.471	0.445	0.344	0.328	0.622	0.620	0.440	0.437	0.931	0.895	0.889	0.860
5	22.0	90.9	0.51	0.0	0.577	0.549	0.508	0.481	0.469	0.438	0.345	0.328	0.621	0.618	0.441	0.436	0.930	0.890	0.887	0.856
6	22.0	86.0	0.15	0.0	0.577	0.538	0.508	0.472	0.469	0.430	0.349	0.326	0.617	0.613	0.441	0.433	0.930	0.883	0.881	0.853
7	22.0	86.0	0.92	0.0	0.572	0.525	0.502	0.461	0.468	0.420	0.349	0.324	0.611	0.606	0.440	0.429	0.921	0.874	0.874	0.844
8	22.0	89.3	1.02	0.0	0.564	0.510	0.496	0.448	0.460	0.409	0.350	0.319	0.605	0.593	0.436	0.420	0.911	0.860	0.866	0.836
9	22.0	86.9	0.25	0.0	0.557	0.498	0.489	0.438	0.454	0.400	0.352	0.317	0.597	0.583	0.432	0.414	0.902	0.848	0.858	0.831
10	22.0	86.9	0.15	0.0	0.553	0.487	0.487	0.429	0.449	0.392	0.350	0.314	0.593	0.576	0.427	0.410	0.900	0.839	0.856	0.823
11	22.0	87.7	0.10	0.0	0.550	0.477	0.483	0.420	0.445	0.384	0.347	0.312	0.587	0.571	0.425	0.407	0.899	0.832	0.854	0.815
12	21.5	94.2	0.10	0.0	0.545	0.467	0.480	0.412	0.443	0.377	0.345	0.311	0.585	0.567	0.422	0.404	0.895	0.825	0.849	0.809
					0.540	0.462	0.477	0.409	0.442	0.375	0.342	0.311	0.582	0.567	0.419	0.404	0.892	0.823	0.843	0.807
Mean	22.3	87.9	0.39	0.0	Ave. error	0.052		0.046		0.047		0.026		0.011		0.012		0.050		0.030

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on April 17.

Experimental and Calculated Average Moisture Content Values

(May 4, 1973) Environmental Conditions					Test Number* 1	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					2.000	2.000
1	24.0	90.9	0.66	---	1.987	1.973
2	25.5	73.8	0.56	---	1.877	1.944
3	28.0	71.4	0.51	40.4	1.828	1.913
4	28.5	68.9	0.66	50.6	1.787	1.863
5	28.5	66.1	0.72	64.2	1.714	1.803
6	30.0	62.4	1.44	65.7	1.616	1.669
7	27.5	73.0	2.62	12.2	1.485	1.469
8	23.5	92.1	1.90	6.1	1.461	1.373
9	21.5	95.0	2.00	4.7	1.428	1.285
10	22.0	91.7	0.61	1.4	1.387	1.268
Mean	25.9	78.5	1.17	30.7	Ave. error	0.084

* Identifications of the test numbers are given in pages 207 to 213

(May 5, 1973)** Environmental Conditions					Test Number* 1	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.314	1.314
1	24.5	76.7	0.92	21.8	1.273	1.258
2	25.5	67.3	0.77	50.3	1.220	1.197
3	26.5	60.0	0.56	55.0	1.151	1.136
4	29.0	54.3	1.08	73.0	1.118	1.031
5	30.0	55.9	1.59	63.1	0.938	0.908
6	31.0	52.7	1.18	63.0	0.844	0.803
7	29.5	60.8	3.24	36.3	0.726	0.660
8	28.0	61.6	2.46	26.4	0.604	0.567
9	26.5	60.0	2.10	---	0.481	0.497
Mean	27.8	61.0	1.54	48.7	Ave. error	0.043

* Identifications of the test numbers are given in pages 207 to 213

** Continuation of experiment on May 4.

(May 9, 1973) Environmental Conditions					Test Number* 1	
Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					2.007	2.007
1	25.0	61.6	0.87	57.6	1.913	1.940
2	27.0	55.9	0.97	58.8	1.789	1.851
3	28.5	48.6	1.18	61.9	1.681	1.728
4	29.5	46.6	1.33	61.7	1.536	1.582
5	29.5	43.7	2.16	34.6	1.318	1.369
6	29.0	47.0	2.88	32.2	1.083	1.135
7	30.0	46.1	3.24	36.4	0.836	0.909
8	29.5	46.1	2.88	27.4	0.673	0.737
9	27.0	52.7	3.24	1.7	0.525	0.602
10	25.5	56.7	1.64	0.0	0.449	0.537
Mean	28.05	50.5	2.04	37.2	Ave. error	0.060

* Identifications of the test numbers are given in pages 207 to 213

Experimental and Calculated Average Moisture Content Values

(May 14, 1973)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* $\bar{M}^1_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.943	1.943
1	30.5	55.9	0.72	35.2		
					1.843	1.872
2	30.0	56.7	1.13	21.1		
					1.700	1.760
3	29.0	60.0	1.44	13.8		
					1.520	1.626
4	28.0	60.8	1.13	8.9		
					1.383	1.520
5	26.5	64.9	1.02	4.8		
					1.280	1.434
6	25.0	72.2	0.61	1.5		
					1.235	1.389
Mean	28.2	61.8	1.01	14.2	Ave. error	0.116

* Identifications of the test numbers are given in pages 220-226

(May 15, 1973)**

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	(Test Number* $\bar{M}^1_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.955	0.955
1	24.5	67.3	0.36	38.6		
					0.911	0.923
2	28.5	57.5	1.13	60.9		
					0.831	0.835
3	31.0	47.8	1.08	73.7		
					0.740	0.732
4	30.5	50.2	1.54	44.3		
					0.651	0.632
5	32.0	45.3	1.80	68.7		
					0.551	0.526
6	33.0	43.3	1.18	29.1		
					0.480	0.444
7	32.5	45.3	1.13	29.6		
					0.420	0.381
8	32.0	46.1	1.54	32.0		
					0.347	0.324
9	30.0	58.4	2.46	9.4		
					0.303	0.282
Mean	30.4	51.3	1.36	42.9	Ave. error	0.023

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on May 14.

Experimental and Calculated Average Moisture Content Values

(May 21, 1973)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* $\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.935	1.935
1	27.0	68.6	0.51	32.8		
					1.729	1.870
2	28.0	68.6	0.66	27.0		
					1.667	1.796
3	29.0	79.6	1.64	36.7		
					1.625	1.709
4	30.0	69.3	1.18	27.6		
					1.519	1.614
5	28.5	79.6	1.90	24.1		
					1.469	1.523
6	29.5	71.4	1.85	34.4		
					1.400	1.417
7	31.0	61.7	1.85	28.7		
					1.335	1.288
8	29.5	65.2	1.02	5.8		
					1.248	1.187
9	27.0	77.5	1.44	2.6		
					1.057	1.115
Mean	28.8	71.3	1.34	24.4	Ave. error	0.084

* Identifications of the test numbers are given given in pages 220-226

(May 22, 1973)**

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* $\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.942	0.942
1	24.0	85.1	0.82	20.2		
					0.889	0.904
2	26.5	72.7	0.36	38.3		
					0.858	0.848
3	29.5	63.1	0.66	64.5		
					0.790	0.768
4	31.0	55.9	1.13	49.9		
					0.713	0.670
5	31.0	59.0	1.38	50.0		
					0.637	0.587
6	32.0	56.9	1.18	36.9		
					0.568	0.508
7	32.0	54.8	0.92	42.4		
					0.469	0.438
8	32.5	56.9	2.00	37.8		
					0.370	0.376
9	30.0	60.3	2.67	22.4		
					0.301	0.331
Mean	29.8	62.8	1.24	40.3	Ave. error	0.034

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on May 21.

Experimental and Calculated Average Moisture Content Values

(May 25, 1973)

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* $\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					1.992	1.992
1	24.5	75.5	0.77	30.7		
					1.913	1.929
2	27.0	70.0	0.66	41.7		
					1.850	1.861
3	29.0	56.2	0.92	67.3		
					1.669	1.766
4	29.0	56.2	0.77	61.7		
					1.559	1.667
5	31.0	52.8	1.08	70.6		
					1.472	1.542
6	32.0	51.4	1.08	60.1		
					1.283	1.403
7	32.5	48.7	1.08	34.7		
					1.129	1.251
8	32.0	51.4	0.66	12.1		
					1.035	1.115
9	30.0	54.8	1.44	3.1		
					0.929	0.991
10	27.5	68.6	2.16	8.2		
					0.826	0.902
Mean					Ave.	
	29.5	58.6	1.06	39.0	error	0.084

* Identifications of the test numbers are given in pages 220-226

(May 26, 1973)**

Hour	Enviromental Conditions T °C	RH %	u m/sec	R_i cal/cm²hr	Test Number* $\bar{M}_{exp.}$ d.b.	$\bar{M}_{cal.}$ d.b.
					0.677	0.677
1	26.0	69.3	0.46	28.5		
					0.614	0.629
2	27.0	63.1	0.77	50.1		
					0.562	0.572
3	30.0	58.3	1.02	50.0		
					0.496	0.504
4	32.0	53.5	0.87	64.1		
					0.472	0.433
5	32.0	51.4	0.97	45.4		
					0.362	0.371
6	32.0	50.7	1.08	52.2		
					0.283	0.317
7	33.5	48.0	1.69	43.2		
					0.204	0.267
8	32.0	50.7	2.62	22.4		
					0.188	0.230
9	29.5	58.3	3.03	7.0		
					0.165	0.208
					Ave.	
Mean	30.4	55.9	1.39	40.3	error	0.034

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on May 25.

Experimental and Calculated Average Moisture Content Values

(May 29, 1973)

Hour	Environmental Conditions T	RH	u	R_i	Test Number* $\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.
					2.078	2.078
1	25.5	85.8	0.25	18.3		
					2.037	2.036
2	25.5	82.4	0.77	19.0		
					1.979	1.977
3	27.0	72.0	0.36	33.8		
					1.913	1.921
4	29.5	62.4	0.66	4.6		
					1.830	1.843
5	30.5	62.4	0.51	31.0		
					1.756	1.759
6	30.0	61.7	0.72	51.2		
					1.652	1.666
7	30.5	61.0	1.49	36.7		
					1.487	1.548
8	29.5	68.6	2.21	23.3		
					1.280	1.430
9	27.0	69.3	2.31	15.7		
					1.198	1.320
10	26.0	76.8	1.02	1.8		
					1.161	1.251
Mean					Ave. error	
	28.1	70.3	1.03	23.5		0.070

* Identifications of the test numbers are given in pages 220-226

(May 30, 1973)**

Hour	Environmental Conditions T	RH	u	R_i	Test Number* $\bar{M}_{exp.}$	$\bar{M}_{cal.}$
	°C	%	$\frac{m}{sec}$	$\frac{cal}{cm^2 hr}$	d.b.	d.b.
					0.888	0.888
1	25.0	82.4	0.36	19.9		
					0.859	0.851
2	28.5	69.3	0.36	46.2		
					0.814	0.787
3	30.5	62.41	0.92	41.2		
					0.743	0.704
4	28.0	62.5	1.49	38.8		
					0.665	0.635
5	24.5	78.9	2.00	13.1		
					0.644	0.595
Mean					Ave. error	
	27.3	71.6	1.02	31.8		0.033

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on May 29.

Experimental and Calculated Average Moisture Content Values

(June 1, 1973)

Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$M^{1}_{exp.}$ d.b.	$M_{cal.}$ d.b.
					1.962	1.962
1	27.5	74.8	1.28	53.7		
					1.880	1.883
2	29.0	67.9	1.02	56.8		
					1.805	1.798
3	30.5	60.3	1.13	52.6		
					1.686	1.694
4	31.5	59.0	1.18	54.3		
					1.555	1.577
5	32.5	57.6	1.18	47.5		
					1.417	1.447
6	31.5	56.9	0.72	25.8		
					1.298	1.327
7	31.5	57.3	1.59	23.6		
					1.119	1.191
8	30.5	62.1	2.05	9.2		
					0.999	1.068
9	28.0	67.9	2.26	0.5		
					0.858	0.969
					Ave.	
Mean	30.3	62.6	1.38	36.0	error	0.052

* Identifications of the test numbers are given in pages 220-226

(June 2, 1973)**

Hour	T °C	RH %	u m/sec	R_i cal/cm²hr	$M^{1}_{exp.}$ d.b.	$M_{cal.}$ d.b.
					0.626	0.626
1	23.5	81.7	0.51	19.0		
					0.604	0.600
2	26.5	68.6	0.61	44.3		
					0.559	0.555
3	29.0	61.0	0.77	64.0		
					0.485	0.497
4	31.0	58.3	1.02	66.0		
					0.436	0.436
5	31.0	56.9	1.64	30.4		
					0.373	0.380
6	31.0	57.6	1.44	35.5		
					0.320	0.333
7	31.5	55.5	2.10	32.8		
					0.276	0.290
8	31.5	55.5	3.39	----		
					0.246	0.251
9	30.0	60.3	2.82	----		
					0.242	0.227
					Ave.	
Mean	29.4	61.7	1.59	41.7	error	0.090

* Identifications of the test numbers are given in pages 220-226

** Continuation of experiment on June 1.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System*	Particle Geometric	Initial Load ** (Kg/m^2)
Aug. 31, 1972	1	2	1x1x5 cm	20
	5	2	1x1x5 cm	20
	2	2	1x1x5 cm	20
	4	2	1x1x5 cm	20
	3	9	1x1x5 cm	20
Sept. 1, 1972	1	2	1x1x5 cm	20
	5	2	1x1x5 cm	20
	2	2	1x1x5 cm	20
	4	2	1x1x5 cm	20
	3	9	1x1x5 cm	20
Sept. 2, 1972	1	2	1x1x5 cm	20
	5	2	1x1x5 cm	20
	2	2	1x1x5 cm	20
	4	2	1x1x5 cm	20
	3	9	1x1x5 cm	20
Sept. 14, 1972	2	2	1x1x5 cm	8
	6	2	1x1x5 cm	8
Sept. 21, 1972	2	2	1x1x5 cm	8
	1	9	1x1x5 cm	8
Sept. 29, 1972	1	2	1x1x5 cm	8
	2	2	1x1x5 cm	12
Oct. 5, 1972	2	2	1x1x5 cm	8
	5	2	1x1x5 cm	12
	6	2	1x1x5 cm	16
Oct. 17, 1972	1	2	1x1x5 cm	8
	2	7	large chips	8
	3	2	1x1x5 cm	12
	5	7	large chips	12
Oct. 27, 1972	1	2	1x1x5 cm	8
	5	2	1x1x5 cm	12
	6	2	1x1x5 cm	16
	7	7	large chips	12
	8	7	large chips	16
	4	8	small chips	12
	9	8	small chips	16
March 7, 1973	23	1	1.2x1.2x5 cm	16
	25	1	1.2x1.2x7 cm	16
	24	1	1x1x5 cm	16
	32	1	1x1x7 cm	16

* Drying systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System*	Particle Geometric	Initial Load ** (Kg/m^2)
March 7, 1973	35	2	1x1x5 cm	16
(Continued)	34	2	1.2x1.2x7 cm	16
	29	2	1x1x7 cm	16
	33	2	1.2x1.2x5 cm	16
	6	2	1x1x1 cm	16
March 8, 1973	23	1	1.2x1.2x5 cm	16
	25	1	1.2x1.2x7 cm	16
	24	1	1x1x5 cm	16
	32	1	1x1x7 cm	16
	35	2	1x1x5 cm	16
	34	2	1.2x1.2x7 cm	16
	29	2	1x1x7 cm	16
	33	2	1.2x1.2x5 cm	16
	6	2	1x1x1 cm	16
March 10, 1973	27	1	1x1x1 cm	20
	21	1	1x1x9 cm	20
	31	1	1x1x5 cm	20
	22	1	0.8x0.8x1 cm	20
	99	2	1x1x1 cm	20
	23	2	0.8x0.8x5.0 cm	20
	30	2	1x1x5 cm	20
	2	2	1x1x9 cm	20
	31	2	0.8x0.8x9 cm	20
March 11, 1973	27	1	1x1x1 cm	20
	21	1	1x1x9 cm	20
	31	1	1x1x5 cm	20
	22	1	0.8x0.8x1 cm	20
	99	2	1x1x1 cm	20
	23	2	0.8x0.8x5.0 cm	20
	30	2	1x1x5 cm	20
	2	2	1x1x9 cm	20
	31	2	0.8x0.8x9 cm	20
March 14, 1973	35	1	1x1x5 cm	28
	36	1	1x1x1 cm	20
	33	1	1x1x5 cm	28
	31	1	1x1x5 cm	24
	21	1	1x1x3 cm	20
	34	1	1x1x5 cm	20

* Drying Systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System	Particle Geometric	Initial Load ** (Kg/m^2)
March 14, 1973	23	2	1x1x5 cm	20
(Continued)	32	2	1x1x5 cm	20
March 15, 1973	35	1	1x1x5 cm	28
	36	1	1x1x1 cm	20
	33	1	1x1x5 cm	28
	31	1	1x1x5 cm	24
	21	1	1x1x3 cm	20
	34	1	1x1x5 cm	20
	23	2	1x1x5 cm	20
	32	2	1x1x5 cm	20
March 21, 1973	33	1	1x1x7 cm	20
	34	1	1x1x1 cm	20
	31	1	1x1x5 cm	20
	27	1	1x1x5 cm	16
	36	1	1x1x3 cm	20
	32	1	1x1x5 cm	24
	30	2	1x1x5 cm	20
	29	4	disc bars	20
	35	4	disc bars	20
March 22, 1973	33	1	1x1x7 cm	20
	34	1	1x1x1 cm	20
	31	1	1x1x5 cm	20
	30	2	1x1x5 cm	20
	29	4	disc bars	20
	35	4	disc bars	20
March 24, 1973	34	1	1x1x5 cm	24
	31	1	1x1x1 cm	24
	36	1	1x1x3 cm	24
	27	1	1x1x5 cm	28
	32	1	1x1x3 cm	28
	33	1	1x1x1 cm	28
March 25, 1973	34	1	1x1x5 cm	24
	31	1	1x1x1 cm	24
	36	1	1x1x3 cm	24
	27	1	1x1x5 cm	28
	32	1	1x1x3 cm	28
	33	1	1x1x1 cm	28
	23	2	1x1x5 cm	24

* Drying systems are described after this table

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B2

Physical Charasteristics For Each Test Number

Date	Test Number	Drying System*	Particle Geometric	Initial Load** Kg/m^2
March 28, 1973	31	1	1x1x5 cm	20
	33	1	1x1x8 cm	24
	36	1	1x1x8 cm	24
	34	1	1x1x8 cm	28
	27	1	1x1x5 cm	24
	24	1	1x1x5 cm	16
	32	2	1x1x5 cm	16
	22	2	1x1x5 cm	24
	23	2	1x1x5 cm	20
March 29, 1973	31	1	1x1x5 cm	20
	33	1	1x1x8 cm	24
	36	1	1x1x8 cm	24
	34	1	1x1x8 cm	28
	27	1	1x1x5 cm	24
	24	1	1x1x5 cm	16
	22	2	1x1x5 cm	24
	23	2	1x1x5 cm	20
March 31, 1973	36	3	disc bars	24
	33	1	1x1x2 cm	20
	34	1	1x1x1 cm	24
	31	3	disc bars	20
	27	1	1x1x2 cm	24
	24	1	1x1x1 cm	20
	32	2	1x1x2 cm	16
	22	2	1x1x1 cm	16
April 1, 1973	36	3	disc bars	24
	33	1	1x1x2 cm	20
	34	1	1x1x1 cm	24
	31	3	disc bars	20
	27	1	1x1x2 cm	24
	24	1	1x1x1 cm	20
	32	2	1x1x2 cm	16
	22	2	1x1x1 cm	16

* Drying systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter throught the analysis.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System*	Particle Geometric	Initial Load ** (Kg/m^2)
April 4, 1973	34	3	disc bars	24
	33	1	1x1x5 cm	20
	27	3	disc bars	28
	31	1	1.2x1.2x5 cm	20
	24	3	disc bars	16
	36	3	disc bars	20
	32	2	1.2x1.2x5 cm	20
	22	2	1x1x5 cm	20
April 5, 1973	34	3	disc bars	24
	33	1	1x1x5 cm	20
	27	3	disc bars	28
	31	1	1.2x1.2x5 cm	20
	24	3	disc bars	16
	36	3	disc bars	20
	32	2	1.2x1.2x5 cm	20
	22	2	1x1x5 cm	20
April 7, 1973	24	1	1x1x5 cm	20
	31	1	1.2x1.2x5 cm	20
	33	3	disc bars	20
	36	3	disc bars	24
	27	3	disc bars	16
	34	3	disc bars	28
	29	2	1.2x1.2x5 cm	20
	7	4	disc bars	20
	32	2	1x1x5 cm	20
April 8, 1973	24	1	1x1x5 cm	20
	31	1	1.2x1.2x5 cm	20
	33	3	disc bars	20
	36	3	disc bars	24
	27	3	disc bars	16
	34	3	disc bars	28
	29	2	1.2x1.2x5 cm	20
	7	4	disc bars	20
	32	2	1x1x5 cm	20
April 11, 1973	34	1	1.2x1.2x5 cm	20
	33	3	disc bars	20
	24	1	1x1x5 cm	20

* Drying systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System	Particle Geometric	Initial Load ** (Kg/m^2)
April 11, 1973	27	3	disc bars	24
(Continued)	31	3	disc bars	28
	36	3	disc bars	16
	32	2	1x1x5 cm	20
	29	2	1.2x1.2x5 cm	20
	7	4	disc bars	20
April 12, 1973	34	1	1.2x1.2x5 cm	20
	33	3	disc bars	20
	24	1	1x1x5 cm	20
	27	3	disc bars	24
	31	3	disc bars	28
	36	3	disc bars	16
	32	2	1x1x5 cm	20
	29	2	1.2x1.2x5 cm	20
	7	4	disc bars	20
April 14, 1973	24	1	1x1x5 cm	24
	33	1	1.2x1.2x5 cm	20
	36	3	disc bars	20
	34	1	1.2x1.2x5 cm	24
	31	1	1.2x1.2x5 cm	28
	27	1	1x1x5 cm	20
	32	4	disc bars	20
	7	2	1.2x1.2x5 cm	20
	29	2	1x1x5 cm	20
April 15, 1973	24	1	1x1x5 cm	24
	33	1	1.2x1.2x5 cm	20
	36	3	disc bars	20
	34	1	1.2x1.2x5 cm	24
	31	1	1.2x1.2x5 cm	28
	27	1	1x1x5 cm	20
	32	4	disc bars	20
	7	2	1.2x1.2x5 cm	20
	29	2	1x1x5 cm	20
April 17, 1973	27	1	1.2x1.2x5 cm	24
	34	1	1.2x1.2x5 cm	20
	26	1	1.2x1.2x5 cm	16
	24	3	disc bars	16

* Drying systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B2

Physical Characteristics For Each Test Number

Date	Test Number	Drying System*	Particle Geometric	Initial Load ** (Kg/m^2)
April 17, 1973	33	3	disc bars	24
(Continued)	31	3	disc bars	20
April 17, 1973	27	1	1.2xl.2x5 cm	24
(Night)	34	1	1.2xl.2x5 cm	20
	36	1	1.2xl.2x5 cm	16
	24	3	disc bars	16
	33	3	disc bars	24
	31	3	disc bars	20
	24	2	1.2xl.2x5 cm	20
	7	4	disc bars	20
May 4, 1973	1	5	disc bars	24.5
May 5, 1973	1	5	disc bars	24.5
May 9, 1973	1	5	disc bars	27.6
May 14, 1973	1	5	disc bars	24.5
May 15, 1973	1	5	disc bars	24.5
May 21, 1973	1	6	disc bars	25.6
May 22, 1973	1	6	disc bars	25.6
May 25, 1973	1	6	disc bars	25.3
May 26, 1973	1	6	disc bars	25.3
May 29, 1973	1	6	disc bars	24.8
May 30, 1973	1	6	disc bars	24.8
June 1, 1973	1	6	disc bars	26.4
June 2, 1974	1	6	disc bars	26.4

* Drying systems are described after this table.

** This is the initial load for the first drying day. The initial load is considered as a proportional value of the dry matter through the analysis.

APPENDIX B3

Drying System Nomenclature

Drying System Number	Description
1	Vertical trays loaded with cassava rectangular bars.
2	Horizontal trays elevated 30 cm from the floor. Loaded with cassava rectangular bars.
3	Vertical trays loaded with cassava " disc bars ".
4	Horizontal trays elevated 30 cm from the floor. Loaded with cassava " disc bars ".
5	Vertical drier loaded with cassava disc bars.
6	Vertical drier modified with wings. Loaded with cassava disc bars.
7	Horizontal trays elevated 30 cm from the floor. Loaded with cassava large chips.
8	Horizontal trays elevated 30 cm from the floor. Loaded with cassava small chips.
9	Tray on the floor. Loaded with cassava rectangular bars.

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