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Date 1/5/89

MOISTURE CHARACTERISTICS OF THE CURED
BURLEY TOBACCO LEAF

A Thesis
Presented for the
Degree
Master of Science
The University of Tennessee, Knoxville

William Mickel Davis

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ABSTRACT

Burley tobacco absorption data were collected for environmental conditions experienced in the burley belt during October through December. These data were needed to describe the physical characteristics of the burley leaf in order to apply the information to a moisture determination system. The exponential drying equation was used to model absorption data experimentally determined at temperatures of 0, 5, 10, and 15 °C. Samples were preconditioned in a 12% relative humidity environment, then introduced to either a 55, 75, or 85% relative humidity for absorption until equilibrium was closely approached. An evaluation of the leaf character (order) was determined for each test by physically handling the leaf and comparing it to a scale rating for 'order'.

Drying tests were conducted using a hot-air-blast oven. Preliminary drying tests were developed to investigate the drying characteristics of burley samples containing different moisture contents, particle sizes, and stalk positions. The results of the preliminary tests were used to establish the parameters for the main drying experiments. The samples for the main experiment were initially conditioned in relative humidities of 12, 55, 75, and 85% with particle sizes of 1, 3, 6, and 25 mm from three stalk positions. The times of drying were 3, 5, 7, 9, and 11 min.

A limited test was made to compare the hot-air-blast oven determinations to a 24-h convection oven test.

The moisture absorption results showed that, under the conditions of this experiment, the exponential equation was adequate for describing moisture absorption in the cured burley tobacco leaf. It was concluded that relative humidity has a greater effect on equilibrium moisture content and that temperature has the greater effect on the slope of the absorption curve. It was also concluded that the established character scale could be used to estimate moisture content of samples.

The 3-mm particle size was the optimum size for use in a quick-dry oven. Particle size had a significant effect on the time required to release all moisture in the hot-air-blast oven. The 25-mm shred size was found unacceptable for use in a quick-dry test. Initial sample moisture content had the greatest effect on the amount of moisture removed. It was concluded that a good estimate of the initial sample moisture content would enhance the drying results from a quick-dry oven.

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CHAPTER I

INTRODUCTION

1. BACKGROUND OF THE PROBLEM

The exact moisture content of tobacco at the sale warehouse is a concern to both the buyer and the seller. The buyer wants the moisture content to be as low as possible to avoid paying for extra water and to reduce some of the costs of redrying. The farmer, on the other hand, wants the highest return possible for his crop since it is sold on a weight basis, and a high moisture content increases the weight.

In today's farm economy, most farmers try to have their tobacco in the range of 30-35% moisture content before "stripping". The "stripping" process involves physically removing the leaves from the stalk and sorting them according to their grades and/or position on the stalk. Farmers prefer higher moisture contents to increase the sale weight. At moisture contents above 35%, a pile of tobacco is subject to heating and subsequent fungal rotting; therefore, high-moisture stripping is risky. At present, tobacco grades do not reflect moisture content unless the U.S. Government grader subjectively determines that the tobacco is too moist to be safely stored for a few days. In this case the tobacco is graded "W" or "NO-G" and the farmer must redry the pile before he can sell it. Tobacco

companies immediately redry all purchased tobacco to near 12% dry basis, because tobacco at or below this moisture content is safe from fungi deterioration for prolonged periods of time. The companies store all tobacco for up to three years before it is remoistened to 16-20% for cutting and then redried to 12% for machine manufacture of cigarettes (Welty and Stout, 1970).

The tobacco industry would like to implement a commercial moisture regain standard at the tobacco markets to permit a pricing scale based on the amount of dry tobacco purchased. John, 1987, suggests that an appropriate moisture content level for marketing would be 15-16% with price adjustment around this value. The pricing system might pay a premium for tobacco below the set moisture level with a reduced price as the moisture content increased above the set level. Implementation of such a system would depend upon the development of a rapid moisture measurement system which can be effectively applied at the tobacco markets.

An appropriate moisture determination system could help bring the buyer and seller together. An acceptable system must satisfy the pricing system, handling procedures, low technical level labor, and hold down marketing costs by being accurate, fast, relatively inexpensive, and easy to use. It must be quick because many samples will be tested in a short period of time as the farmers weigh-in their crops at the sale warehouse. More than one system would

probably be used at each warehouse so it must be affordable. The system must be easy to use since the operators can be expected to have low technical expertise.

The moisture in tobacco affects the physical properties and the quality of the final product. Physical properties of cured tobacco leaves which are highly sensitive to moisture content include brittleness, tensile strength, filling capacity, and thermal diffusivity. The property with the greatest importance at the market is brittleness because of its effect on the handling characteristics of tobacco leaves. As the tobacco leaf absorbs moisture it becomes less brittle and, at or above 20% moisture content dry basis, can be handled without shattering (Casada, et al. 1976). An increase in moisture content increases the tensile strength of tobacco (more force is needed to break a leaf when it is pulled apart), and it causes a reduction in filling capacity because more tobacco can be compressed into a space with a given force. Thermal diffusivity measures the ease with which heat travels through a given substance. Tobacco with a high moisture content has a higher thermal diffusivity than does dry tobacco.

Most farmers depend on natural atmospheric conditions to bring the leaves to an adequate moisture level (order). This "order" causes the leaf to become pliable and permits handling without shatter loss. This occurs when a relative

humidity of greater than 75% is held for about two days (Walton and Henson, 1970).

There are several different forms of moisture present in tobacco since it is a biological material. These include free water, physically bound water, chemically bound water, and intracellular water. Free water condenses on the surface of the leaf, while physically bound water absorbs into the pore spaces of the leaf as water vapor. Chemically bound water is actually part of the chemical makeup of the leaf. The intracellular water absorbs through the cell wall and enters the cytoplasm (Young, 1975). The physical character (order) of the leaf depends on the free and physically bound water. The other forms are only released if the leaf is chemically reduced. Any moisture measurement system must overcome the inaccuracies caused by these different moisture forms.

The solution to the whole problem of moisture determination at the market will require the full development of equipment and procedures which rely on information such as the results of this study. Before an accurate moisture value from a market package can be obtained, a correct sampling procedure needs to be developed to insure a sample representative of the whole package. These are steps which go beyond the scope of this study.

2. PURPOSE AND OBJECTIVES

The purpose of this investigation was to identify the mechanism of moisture absorption and desorption of the tobacco leaf at typical burley market conditions with specific consideration of the effects that might relate to systems for the measurement of moisture content at the market. The following objectives were designed for this purpose:

1. To experimentally determine selected moisture isotherm points and equilibrium moisture contents of cured tobacco at low temperatures.
2. To establish a scale rating of the leaf character (order) as the leaves absorb moisture.
3. To experimentally determine the nature of rapid moisture removal from cured burley tobacco by a hot-air-blast oven and make a comparison with a standard convection oven.

CHAPTER II

REVIEW OF LITERATURE

1. MOISTURE ABSORPTION

Moisture equilibrium studies of hygroscopic materials have been quite extensive and have resulted in the development of several models to describe the drying, wetting, and equilibrium moisture. Information has been obtained for grain and field crops which can be directly related to tobacco. Other research with tobacco has provided results which more specifically relate to this study.

Non-Tobacco Studies

Young and Nelson (1967) used condensation and evaporation equations from classical kinetic theory of gasses to develop expressions which related equilibrium moisture contents of biological materials to the environmental conditions. They found a hysteresis between the sorption and desorption isotherms. Young (1969) considered both heat and mass-transfer simultaneously in describing the drying process of porous, hygroscopic materials. He used a numerical technique to solve the equations with varying thermal conductivities and moisture diffusivities. He concluded that these equations may

successfully be solved numerically for cases where analytical solutions are not available.

Several researchers have compared different equilibrium moisture content equations using grains and seeds (Chen and Morey, 1988 and Siebenmorgen et al., 1988). They all concluded that the modified-Henderson and Chung-Pfost equations (ASAE Standard D245.4, 1987) can serve as good models for most grains and fibrous materials.

Osborn, et al. (1988) used thin-layer soybean adsorption data to test a model using a form of Page's equation (Page, 1949). They also modeled equilibrium moisture contents using the modified Halsey equation (Halsey, 1948).

Tobacco Studies

Samfield (1957) studied the changes in entropy of various tobaccos at different moisture contents. He concluded that differences in physiol-chemical properties between major tobacco types are caused by differences in their basic cellulose structures, and that the water in burley tobacco is much more restricted than in bright tobacco.

Locklair, et al. (1957) evaluated tobacco moisture absorption data with the Clausius-Clapeyron equation. They used an isosteric (constant moisture content) method in a vacuum to determine the equilibrium moisture contents and isosteric net heats of desorption. The method had the

following advantages over the usual isothermal (constant temperature) procedure: It was rapid because the resistance to diffusion was eliminated in the evacuated atmosphere; the amount of mass transfer involved was small; the heats of desorption (amount of energy needed to drive off the water) could be directly determined from the data; and the method greatly reduced the formation of mold on the tobacco samples.

Locklair, et al. (1958) determined the thermal diffusivities of various tobaccos. These determinations were used for two purposes: first, in the solution of certain heat transfer equations and, second, in obtaining the thermal conductivities. These values could then be combined in a simultaneous heat-mass transfer equation to accurately describe drying of tobacco.

Young (1964) and Young, et al. (1967) used dimensional analysis to derive an empirical expression to describe the wetting process of tobacco by analyzing moisture content versus time. His prediction equation attained a "goodness of fit" which made it a better "estimator" than the standard thin-layer drying exponential equation. The correlation of the exponential equation, however, was at all times significant at the one percent level.

Walton and Henson (1970) obtained moisture absorption data which were highly correlated to the standard exponential drying equation with temperature and relative

humidity effects being apparent. They collected short term (24 h) equilibrium moisture contents which could only be applied to their data. The environmental conditions included temperatures of 40, 50, 60 and 70 °F combined with relative humidities of 75, 85 and 95 percent, which are some of the expected conditions during the burley marketing season. Their environmental cabinets controlled the dry-bulb and dew-point temperatures to ± 1 °F. They obtained good data for the 50, 60 and 70 °F tests, but poor control caused excessive error for the 40 °F tests. They discussed a need for more accurate information at the lower temperatures to describe leaf moisture during the colder handling periods.

Walton (1974) and Walton, et al. (1976) developed separate models for the diffusion of moisture into the lamina and midrib. They used geometric models with heat-mass transfer theory to mathematically describe moisture diffusion. The lamina was described by the infinite thin-sheet model and the midrib by the infinitely long circular cylinder. They obtained a better fit of the data using their mathematically derived equations for every environmental condition during sorption than they did with the exponential equation. The derived models estimated the sorption data with a standard error which was about one-third that of the exponential equation. The exponential

equation, however, better estimated desorption data, especially at high humidities.

Samejima, et al. (1978) analyzed moisture absorption isotherms of several Japanese burley varieties by the Brunauer, Emmett and Teller's infinite layer adsorption equation in the humidity range of 5 to 80%. They also investigated the relationship between the amount of water-soluble substances and the equilibrium moisture content by adding either sucrose or glycerol to a shredded sample. The addition of water-soluble substances caused the moisture content to greatly increase except at a low range of humidities. The increment of moisture increase and the quantity of additives used were directly proportional. Supporting evidence for their results came from the fact that moisture sorption capacities of bright tobaccos are much higher than those of air-cured tobaccos. Flue-cured tobaccos have sugar contents approaching 20% while air-cured tobaccos rarely exceed 1%.

Crump (1982) studied moisture sorption isotherms of both free and physically bound water in tobacco and cellulose. Data from nuclear magnetic resonance studies have shown that these types of water are the primary sources of moisture content in all biological materials. These studies showed two distinct energy levels corresponding to the two moisture forms. The lower energy level corresponded to adsorbed (surface) water while the higher energy level

corresponded to absorbed (internal or physically bound) water. Crump modified the Brunauer, Emmett and Teller's isotherm equation by adding a component to describe the absorption of water.

Swetnam, et al. (1982) and Casada, et al. (1985) used the moisture diffusion equation to describe moisture diffusion from densely packed bales of burley tobacco. They found that the mass diffusivity of densely packed burley leaves was a function of the direction of diffusion relative to the leaf lamina, the initial moisture content of the tobacco, the temperature of the drying air, and the stalk position. Moisture was found to diffuse parallel to the packed leaves much easier than in the perpendicular direction. This indicated that most moisture is lost at the sides and ends of packed bales.

Samejima, et al. (1984) studied the moisture permeability of cured tobacco epidermis (leaf surface). They found that moisture transfers through both the stomata (pores through which a living leaf exchanges gasses with the atmosphere) and the cuticular layer (the smooth, waxlike surface of the leaf) with the majority going through the cuticular layer. The cuticular layer was the limiting factor to the moisture transfer rate through cured tobacco epidermis.

Samejima and Yano (1985) investigated the moisture diffusion within shredded tobacco leaves. They varied the

shred width from about 2 mm to 20 mm and found a large variation in moisture diffusion rates. When the shred width was 10 mm, the sorption rate through the cut faces of the shred was low as compared to the epidermis. On the other hand, a shred width of 2.5 mm caused the moisture sorption rate through the cut faces to equal that through the epidermis. Shred widths below 2.5 mm gave much greater sorption rates through the cut faces than through the epidermis.

Walton and Casada (1986) developed a new diffusion model which was based on the geometry of the cells of burley tobacco leaves. They represented the palisade cells by the infinite cylinder, the mesophyll cells by the sphere and the epidermal layer by a constant resistance in boundary condition. They concluded that this model was superior to previous models which assumed the lamina and midrib to be homogenous materials.

Walton, et al. (1986) studied moisture diffusion pertaining to the geometric shapes of the infinite plate, infinite cylinder, and sphere as a function of the Fourier and Biot numbers for mass transfer. They developed moisture diffusion charts and tables for each of the geometric shapes as a function of both Fourier and Biot numbers. Their tables provide an approximate fit to experimental data where internal and external resistances to moisture diffusion are allowed to vary.

Studies With Special Impact on This Research

The several physical and environmental characteristics which have a major influence on the moisture transfer into and out of burley tobacco leaves include leaf thickness, pore space, density, difference between equilibrium and initial moisture contents, vapor pressure, specific leaf surface area, and time (Samejima, et al., 1984 and Young, et al., 1967). Young used most of these factors in a dimensional analysis to develop the following general equation for all slab like materials:

$$\theta T = C[X/V](P)^e[\sigma_t/\sigma_w]^f(\theta M)^g \dots \dots \dots [1]$$

where:

θT = time between the initial subsection of a leaf to a wetting environment and the instant at which a new equilibrium is reached,

C = dimensionless proportionality constant,

X = leaf thickness,

V = velocity of the water vapor,

P = percentage pore space based on bulk volume of the leaf,

σ_t = dry matter density of the tobacco leaf,

σ_w = density of the water vapor,

θM = difference between equilibrium moisture content and initial moisture content expressed as a percentage of the oven-dry weight, and

e, f, g = exponents to be experimentally determined.

Equation [1] was simplified to the following equation which removed all the constant terms:

$$[M_e - M / M_e - M_0] = [t_e - t / t_e]^h \dots \dots \dots [2]$$

where:

- M_e = equilibrium moisture content, percent,
- M = moisture content at time, t , percent,
- M_0 = initial moisture content, percent,
- t_e = time at which equilibrium moisture content is reached, h,
- t = any general time, $t_e \geq t \geq 0$, h, and
- h = exponent to be evaluated.

Young obtained good results with this equation when estimating moisture uptake of burley tobacco. The equation gave a "goodness of fit" better than the exponential thin-layer drying equation generally used; however, the correlation of the exponential equation was at all times significant at the one percent level. The following standard exponential equation can be interpreted in terms of the environmental factors affecting the absorption process:

$$[M - M_e / M_0 - M_e] = \exp^{-kt} \dots \dots \dots [3]$$

where:

- M = moisture content at time, t , percent,
- M_0 = initial moisture content, percent,
- M_e = equilibrium moisture content, percent,

k = wetting constant, h^{-1} , and

t = wetting time, h .

The moisture ratio of equation [3] may be solved for moisture content at time, t , to obtain:

$$M = M_e - (M_e - M_0) \exp^{-kt} \dots \dots \dots [4]$$

Further simplification gives an equation of the form:

$$M = B_1 - B_2 (\exp^{-B_3 t}) \dots \dots \dots [5]$$

where:

B_1 = equilibrium moisture content, percent,

B_2 = equilibrium minus initial moisture content,
percent,

B_3 = wetting constant, h^{-1} , and

t = time, h .

This equation allows estimation of the equilibrium moisture content and the wetting constant.

Walton (1974) included the leaf geometry along with the physical characteristics in his mathematical analysis of the burley leaf. He modeled the lamina using the infinite plate and the midrib using the infinite circular cylinder. The lamina model was of the form:

$$\theta(t) = \sum [2/(\delta_n L)^2] \exp^{-D \delta_n^2 t} \dots \dots \dots [6]$$

where:

D = diffusion coefficient based on the mass of water per unit mass of solid, cm^2/s ,

t = time, s,

$\delta_n = (2n+1)\pi/2L$,

$n = 0, 1, 2, \dots$,

L = half thickness of lamina, cm, and

$\theta(t)$ = moisture ratio at time, t .

The midrib model was of the form:

$$\theta(t) = \sum [2/(\beta_n R)^2] \exp^{-D\beta_n^2 t} \dots \dots \dots [7]$$

where:

D = diffusion coefficient based on the mass of water per unit mass of solid, cm^2/s ,

β_n = n th positive root of $J_0(\beta_n R) = 0$,

$J_0(\beta_n R)$ = Bessel function of order zero, and

R = radius of the midrib, cm.

He concluded that the mathematically derived equations were more accurate than the exponential equation when predicting absorption. The exponential equation was more accurate when predicting desorption. His equilibrium moisture content data were obtained from tabulated results of a long-term moisture content experiment done by a previous researcher.

Walton and Henson (1970) used the short-term equilibrium moisture content values reached at the end of their tests (24 h) in the exponential equation. They obtained a very good fit to the data, although the

equilibrium values used were too low. Given enough time for a close approach to equilibrium moisture content, the exponential equation should give satisfactory results when describing moisture uptake and equilibrium moisture content of burley tobacco. The moisture absorption curve should be constant for 24-48 hours before ending a test to insure a close approximation.

Previous researchers have shown different moisture contents for different conditions. Jeffrey (1941) stated that temperatures of 55, 65, and 75 °F showed no significant difference in the amount of moisture absorbed into burley tobacco. His data showed an equilibrium moisture content of 35% dry basis at the 85% relative humidity condition. Walton (1974) stated that moisture contents for the 55, 65, and 75 °F temperatures at the 85% relative humidity were 46.8, 38.5, and 30.2% dry basis respectively, which gives an average value similar to that of Jeffrey. The expected equilibrium moisture contents for the 0, 5, 10, and 15 °C temperatures at 85% relative humidity were in the range of 35-40% dry basis. The expected value for the 75% relative humidity condition was in the 20-25% dry basis range and the expected value for the 55% relative humidity condition was in the 10-15% dry basis range.

2. MOISTURE DETERMINATION METHODS FOR BIOLOGICAL MATERIALS

Moisture measurement of inorganic materials is usually

regarded as a simple analytical procedure, but the moisture measurement of biological materials can be a complex problem because of the many variables affecting the properties of the material. Most material properties vary directly with the amount of moisture present. All methods of moisture measurement, whether direct (measures the volume of water driven off) or indirect (measures the change of some property of the material), have difficulty determining the "true" moisture content. There is no current "standard" moisture measurement method by which all other methods may be calibrated (Bunn, et al., 1970 and McClure, 1975).

The complexity of absorbed moisture in a biological material is caused by the four forms of water present. The moisture forms may affect various properties of the material in different ways, thus, complicating calibration procedures for any device (Young, 1975). Also, measurements which correctly represent the total population depend upon good sampling technique and proper blending of the sample.

Methods of Moisture Measurement

Research with several moisture determination methods has yielded some accurate laboratory data for biological materials, but no method has met the criteria for a tobacco warehouse measuring system.

The methods include the following:

1. Oven,

2. Distillation,
3. Desiccant,
4. Chemical,
5. Gas Chromatography,
6. Electrical,
7. Spectrophotometric,
8. Nuclear,
9. Equilibrium Relative Humidity, and
10. Microwave Heating.

Oven Methods. Three oven methods which are in use in industry and research for the measurement of both organic and inorganic moisture contents include the convection, vacuum, and hot-air-blast methods. They are the most widely used methods for moisture determination and are based on drying known weights of material (direct) and calculating moisture content from the weight loss. No standard method exists for tobacco; however, tobacco companies use a convection oven set at 100 °C for 16 h. All methods are calibrated to the 16-h convection oven (Easterly, 1987 and Mitchum, 1987).

Fryd and Kiff (1951) studied the effects of four different temperature and time settings on the composition of homogenized cigarette tobacco with a convection oven. They found that a temperature of 100 °C for a 24-h or greater period of time not only removed the moisture, but

also resulted in a chemical reaction in which chemically bound moisture from the sample is lost. Their results were empirical in nature because they depended on the size of the sample particles, the drying temperature, the time of drying, the initial moisture content of the sample, and the pressure within the oven. Additionally, it was nearly impossible to remove all the moisture without driving off some of the volatiles (sugars, nicotine, tars, etc.) or causing actual decomposition of the leaf material by oxidation or burning. They reported that the best expectation from an oven method was a set of consistent, repeatable data in which the effect of chemical breakdown is minimized and standardized. A set of criteria was established that should be met by a tobacco oven moisture determination system for revenue purposes. The criteria were as follows:

- (1) Ventilation sufficient to insure that at no time is evaporation from the surface of the tobacco itself slowed down, or allowed to occur at a high rate of velocity in the liquid phase.
- (2) Constancy of final temperature within the oven.
- (3) Identity of heat history for all the samples during the process of drying.
- (4) Speed in dealing with a large number of samples.
- (5) Economy of the time of skilled operatives, which in effect means drying overnight so that the working period may be devoted to weighing. This requirement itself necessitates that the oven shall be fully automatic.

Several technical societies have proposed standard procedures for moisture determination using the convection oven, which is the most used oven method. The American Society of Agricultural Engineers (ASAE) has proposed a standard for tobacco moisture determination which specifies using a convection oven set at $100\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ for 24 h.

Welty and Stout (1970) compared a convection oven using three different temperature-time combinations with a freeze-dry method. The three temperature-time combinations were $40\text{ }^{\circ}\text{C}$ for 7 days, $100\text{ }^{\circ}\text{C}$ for 16 h and heating in a forced-air oven at $130\text{ }^{\circ}\text{C}$ for 3 h. They used shredded tobacco samples cut into 1-mm wide ribbons of varying lengths. They concluded that the different methods had a definite influence on moisture content determinations:

.....Moisture content increased as higher drying temperatures of shorter duration were used. Either the high drying temperatures volatilized substances other than water and their loss accounts for the additional weight loss or moisture was not removed completely by the low drying temperatures.

They suggested using the $100\text{ }^{\circ}\text{C}$ - 16-h method since it was nearest to the average of the four methods used.

Bunn, et al. (1980) suggested using a convection oven set at $100\text{ }^{\circ}\text{C}$ for 24 h when determining the dry matter weights of green burley tobacco. They said that this temperature and time was more widely used in standard procedures for more thermally stable materials.

The vacuum oven method permits a lower temperature than the convection oven because the air is evacuated from the chamber. It causes less dry matter loss, and a test can be completed in less than five hours. The Association of Analytical Chemists (1970) has a vacuum oven standard for grain moisture content. The procedure requires grinding the sample to pass a No. 20 sieve and drying at 99 ± 1 °C at a pressure less than 25 mm of mercury for a period of four hours.

Mitchum (1987) stated that the hot-air-blast oven has seen limited use in the tobacco industry as a quick and accurate method. This method uses a high temperature (130-150 °C) stream of air through the sample to give a quick (4-6 min.) and direct determination of moisture content. Possible adaptation to a tobacco warehouse measurement system would require a careful study of the effects of the high temperatures on the loss of dry matter, especially for samples with different histories.

Distillation Methods. Three distillation methods have been used in previous tobacco moisture research. These include the Brown-Duval, Toluene, and Dexter Oil distillations. All methods require the samples to be added to the solution and heated until all moisture is driven off.

Brown and Duval (1907) placed their sample into 100 cc of hydrocarbon oil at 190 °C and boiled away the moisture. The moisture was subsequently condensed in a separate

container and weighed for a direct determination of moisture content. The method was highly arbitrary and the exact procedure for each kind of material was different. Bidwell and Sterling (1925) showed that the toluene method can be more accurate than oven methods. The time needed for a moisture determination is one hour for most materials and a laboratory set-up is needed. Dexter (1948) simplified the Brown-Duval method by directly weighing the moisture loss without the condensing step. He used vegetable oil heated to 190 °C to give an approximation of the moisture content. The laboratory requirements and potential inaccuracies of these methods prevent them from being practical for revenue purposes in a tobacco warehouse system.

Desiccant Method. The desiccant drying method involves placing a weighted, finely ground sample in a closed container with a large quantity of desiccant material. The desiccant material holds the relative humidity of the air in the container to near 0%, and it absorbs the moisture released by the sample. The AOAC (1970) official method of grain moisture determination involves holding the sample in a vacuum under the presence of anhydrous sulfuric acid until a constant weight is attained. It requires several days for the weight to stabilize, therefore, the method is unsuitable for revenue purposes.

Chemical Methods. Moisture determination by chemical methods are based on stoichiometric chemical reactions which

use water from the sample as one of the reactants. These are the most accurate methods of moisture measurement available. The four methods being used are the Karl Fischer, Calcium Carbide, Calcium Hydride, and Dichromate.

Fischer (1935) developed a titration method which is the most accurate moisture determination method. The method extracts water from a finely ground sample with anhydrous methanol; then, the extract is titrated with a reagent containing iodine, sulfur dioxide, and pyridine. The limiting factors of the method are the time and extensive laboratory set-up required for a determination. Parks (1941) mixed calcium carbide with grain samples and measured the weight loss as the sample water reacted with the calcium carbide to form acetylene gas. The method, however, gave poor results when the sample moisture content was below 40%. Calcium Hydride may be used in place of calcium carbide to double the sensitivity to moisture change. Precise control of temperature, pressure, and volume are needed for high accuracy. Launer and Tomimatsu (1952) added sulfuric acid to a material sample which was mixed with a potassium dichromate solution. The resulting reaction between the dichromate and the dry matter allowed a measure of the amount of dry matter when the solution was titrated with ferrous ammonium sulfate solution. The method must be re-calibrated with each different sample and gives poor results with low moisture content samples.

Gas Chromatography. Weise, et al. (1965) used a gas chromatography method to determine moisture in grains. The method used methanol extracted water, as in the Karl Fischer method, for analysis by gas-liquid chromatography. The method was shown to be very accurate; however, the complexity and high cost of the equipment make it unsuitable for tobacco warehouse applications.

Electrical Methods. Electrical moisture measurement of tobacco depends on the electrical properties of the tobacco itself (Henson, 1962 and Henson and Hassler, 1965). These properties are influenced by several factors such as packing density, leaf orientation, temperature, stalk position, leaf chemistry, and moisture content. Electrical meters are based on the properties of conductance, capacitance, or a combination of the two at various sampling frequencies (Leroy, 1965).

Conductance meters measure the resistance or conductance of a sample which is placed between two electrodes. These meters can be based on either direct or alternating current. Zelany (1954 and 1960) found that conductance meters could only measure moisture contents in the range of 7-23%. He also noted that a sample has to have uniform moisture distribution before good accuracy can be obtained. Hunt (1965) found that conductance meters only measure the "free" water in a sample and the ratio of "free" to bound" water must remain constant for an accurate

moisture determination. McDonald (1976) used two commercially available conductance meters and an experimental one in determining moisture contents of windrowed hay. He found that a stable sample density was important in obtaining accurate results. He concluded that these meters did not provide the accuracy needed for on the farm use since they had to be recalibrated each time a new field, type of crop, or time of day was encountered. Henson, et al. (1984) evaluated two commercially available conductance meters for measuring tobacco moisture content. One meter used alternating current while the other used direct current. They found that these meters were significantly affected by the tobacco density and moisture content, and their uncertainty in moisture determination was three times as great as the convection oven method.

Capacitance meters are more dependant on sample density than are conductance meters; therefore, reproducible data are difficult (Hughes, et al., 1965). They can, however, measure over a wider range of moisture contents and are more accurate when uneven sample moisture is encountered. Nickell, et al. (1981) qualitatively described the dielectric constant and a.c. conductivity of tobacco. They found that at all moisture contents, the dielectric constant decreased with increasing frequency, and increased with increasing moisture content. Also, the conductivity increased uniformly with increasing frequency. However, the

conductivity did not increase uniformly at lower frequencies and increasing moisture content. Henson, et al. (1984) evaluated a commercially available dielectric meter for measuring tobacco moisture content at the sale warehouse. They found that the meter had lower sensitivity to moisture content as the temperature was lowered; therefore, it would not give accurate results during cold days at the warehouse. Use of multiple frequency techniques has allowed measurements made at separate frequencies which are statistically independent. This allowed a reduction in the variance from the mean of the predicted moisture content over a single measurement. Nickell and Henson (1984) used a two-frequency tank circuit in the Mhz range to obtain the ratio of tobacco capacitance properties. This ratio was in direct proportion to the moisture content. They obtained an accuracy of $\pm 6\%$ moisture content for a single reading. Nickell and Henson (1985) used multiple-frequency electric fields to measure the dielectric constant of burley tobacco. The capacitance of a substance depends on the dielectric constant. They found the relative dielectric constant at 69.2 and 100 Mhz was the best prediction of moisture content of both shredded and cored tobacco leaves.

Spectrophotometric Methods. The spectrophotometric methods involve measurement of the different energy states of the water molecule (Kaye, 1954 and McClure, 1968). Each moisture form present in biological materials has a

different energy state and wavelength. The different wavelengths are determined and then correlated to the moisture content. The two primary methods used with biological materials are infrared spectroscopy and microwave spectroscopy.

Hart, et al. (1962) compared near-infrared spectroscopy to the Karl Fischer method using grain samples. They considered the Fischer method as the standard and fitted a linear regression equation to the near-infrared data. They obtained a standard deviation from regression of $\pm 0.24\%$ moisture content dry basis. Norris and Hart (1965) investigated several infrared absorption bands of grain and seeds. They related the difference between the 1.94 and 2.08- μm absorption bands to the moisture content of the material. Their calibration curves showed an accuracy of $\pm 0.5\%$ moisture content in the range of 0-20%. Beutler (1965) used a two-wavelength infrared backscatter system to determine moisture content in paper. His data were calibrated to a convection oven method. He measured moisture contents in the range of 0-12% wet basis and found that the method was as accurate as the oven method. The precision of the device at 5% moisture content was $\pm 0.1\%$. This device does not have to physically touch the sample and is not dependant on sample density; however, the complexity and cost of the system make it unsuitable as a tobacco warehouse method. McClure, et al. (1968) used an

experimentally developed instrument to measure the fluorescence of pulverized tobacco samples. Their data was primarily used to help describe the various chemical components of tobacco. McClure (1968) found that the 1.94- μm wavelength band appeared to most accurately describe moisture contents of flue-cured tobacco in the range of 0-100% dry basis.

Near-infrared spectroscopy is currently being used in both the paper and tobacco industries as a production line moisture measurement system (Easterly, 1987). The system places an infrared beam on the material as it passes by on a conveyor belt. The amount of infrared energy absorbed by the sample is measured and correlated to the moisture content. This system is very accurate when used to measure samples with low moisture variability. When used with highly variable samples, it has to be constantly recalibrated; thus, the method is unsuitable for warehouse measurements.

Microwave spectroscopy involves measuring the amount of microwave energy being attenuated (absorbed) by a sample which may be correlated to the moisture content. This method does not destroy the sample and is quick, but it is too complex and expensive as a tobacco warehouse system.

In a series of papers, Pullman, et al. (1965) described the use of a microwave attenuation device for measurement of tobacco moisture. A large number of samples were measured

with the device, and then the same samples were analyzed by an accepted laboratory method to establish a calibration. A family of curves of moisture content versus microwave attenuation at intervals of temperature were established. They had standard deviations as low as 0.1% moisture contents when careful procedures were followed. Gorakhpurwalla, et al. (1975) studied microwave dissipation losses in high moisture grain using frequencies ranging from 0.9 Ghz to 7.5 Ghz. They found that dissipation losses increased with moisture contents at all frequencies and temperatures tested. They suggested using microwave energy at a frequency of 2.45 Ghz over the moisture range of 20-40% when designing a drying system.

Nuclear methods. These methods measure properties of the atomic nucleus of the water molecule. The two methods used for moisture measurement are Nuclear Magnetic Resonance and Neutron Scattering. Nuclear Magnetic Resonance measures moisture by detecting hydrogen nuclei within the material. A sample is placed in a magnetic field which magnetizes the hydrogen nuclei. The amount of magnetization is then measured and converted into a voltage which is proportional to the moisture content (Rollwitz, 1965). This method is very expensive and its use is restricted to a laboratory setting.

Nickell, et al. (1981) used nuclear magnetic resonance to study the degree of moisture binding in burley tobacco in

different states of moisture content. They found that below 12% dry basis, the signal was too small to be measured. Moisture rates above this level showed a linear relationship with the output signal.

Moisture measurement by the neutron scattering method involves emitting fast neutrons into a sample and then measuring the density of the slow neutrons bounced back by the hydrogen nuclei. Van Bavel (1965) studied soil moisture measurements by neutron scattering. He found that other elements besides hydrogen could also slow down neutrons, thus causing inaccuracies in the measurement of moisture. Calibration of the device is an empirical process since no theoretical relationship between slow neutrons and moisture content has been developed. The device is useful in soil measurements since the calibration does not vary greatly among different soil types. Use of the device for tobacco is unsatisfactory since the variations among tobacco types necessitates recalibration each time a different type is measured.

Equilibrium Relative Humidity. Moisture measurement by the equilibrium relative humidity method involves placing the sample in a closed container and then measuring the relative humidity after equilibrium is attained. The relative humidity obtained can be correlated to a known moisture content for the material (Young 1975). Accuracy of the method is poor at higher relative humidities, and the

actual measurement of relative humidity itself can have considerable error.

Microwave Drying and Heating. Microwave drying uses the microwave energy to drive off the moisture, resulting in a direct determination of moisture. The problems with this method stem from the fact that the high energy microwaves may cause charring of the sample. Gross inaccuracies may be incurred if the sample is dried for too long.

Gorakhpurwalla and Watson (1975) built an experimental microwave applicator to expose samples of high-moisture grain to microwave energy at 2.45 Ghz. Their device combined a hot-air-blast with the microwave energy for more efficient drying. The microwave attenuation was measured for up to eight minutes as the samples were drying. The samples were then placed in a convection oven at 100 °C for 72 h to determine their residual moisture contents. They found that a 40-g sample of high-moisture grain dried to one percent moisture content in 12 min. Hanna and Sharma (1988) used a home microwave oven to determine the times needed to properly dry samples of soybeans. They compared different microwave drying times of the various moisture content samples to a standard convection oven. They used regression analysis to establish a calibration curve between the two methods. They found optimum drying times in the range of 2-3 min depending on the initial moisture contents. This method was limited because the initial moisture contents

have to be known in order to set the correct drying time. This method correlates the temperature rise of a sample heated for a fixed time to the moisture content. The method can use a home microwave oven coupled with a temperature measurement and recording system. Casada, et al. (1983) used a home microwave oven to heat 50-g tobacco samples for 18 s at maximum power of 625 W. They found that the moisture content of tobacco leaves was a linear function of temperature rise. Temperature rise in the sample was uneven because it was whole leaves, and because the oven did not heat evenly. They suggested using shredded samples in a more uniformly heated oven for future tests. Casada and Walton (1984) used shredded tobacco samples to reduce the uneven heating. They obtained an accuracy which was 35% better than the previous whole leaf tests. They stated that the method was accurate if the tobacco was already shredded before absorbing moisture. If whole leaves have to be shredded just before testing, error may be introduced by a change in moisture content caused from heat added during the shredding process.

Method Selected for Testing

All of the moisture measurement methods have some disadvantages when considered for a tobacco market system. The two which most nearly meet the established criteria are the hot-air-blast oven and the microwave heating methods. The microwave method was the most complicated because it

involved using nine thermocouples inserted into the heated samples with readings taken every 30 seconds for several minutes. These readings were averaged and used to develop a parabolic equation for estimating moisture contents. On the basis of the complexity, this method was discarded in favor of the hot-air-blast oven. The oven method lends itself more for use by non-technical personnel.

The literature showed that the same physical and environmental characteristics affected both the moisture absorption and desorption of burley tobacco. Also, the size of tobacco particles, air velocity and temperature, drying time, sample specific heat and thermal conductivity, latent heat of vaporization, and moisture diffusion rate have a major effect on the amount of moisture removed (Chang and Johnson, 1971; Samejima, et al., 1984; and Fryd and Kiff, 1951).

The influence of shred width (particle size) on the rate of moisture transfer into and out of tobacco leaves should have a major influence on the rate of drying (Samejima and Yano, 1985). A 1-mm width allowed moisture transfer three times as fast as does a 6-mm width and twice as fast as does a 3-mm width. Widths greater than 6 mm were shown to not significantly increase moisture transfer. The limiting factor for moisture transfer was the rate of diffusion, therefore, the shorter distance moisture traveled

from center to cut edge in a 1-mm width shred caused the increased moisture removal rate.

The small particle sizes should allow an isothermal drying period similar to that experienced by Chang and Johnson (1970) during curing studies. Their tobacco was initially uncured with as high as 400% dry basis moisture content. The isothermal period resulted when all the heat energy became absorbed by the latent heat of vaporization of the free water at the leaf surface. The much increased moisture transfer rate from the cut faces of the small particles should allow enough moisture to create an isothermal drying period.

CHAPTER III

METHODS AND PROCEDURE

The two phases of this study were: (1) determine selected moisture isotherm points including moisture absorption curves, at low temperatures; and (2) examine the nature of moisture removed from cured burley tobacco at high drying temperatures for a rapid moisture determination.

Both phases of the experiment used tobacco of variety TN-86 grown in the same field at the Greenville, Tennessee Tobacco Experiment Station in 1987. To avoid deterioration, test plants were stored in the laboratory at a temperature of approximately 25 °C and relative humidity in the range of 20-40%. It was assumed that these conditions would reduce variability among leaves which were tested over long periods of time. Test stalks were arbitrarily selected as needed.

1. MOISTURE ABSORPTION EXPERIMENT

The first experiment developed the moisture absorption curves along with the equilibrium moisture contents and a scale rating of the leaf character (order). The character scale was from one to five with one being a very dry (shattering) condition and five a wet or soggy condition.

Methods and Materials

The methods of collecting absorption data for this experiment were similar to the work done by Walton and

Henson (1970). The data, however, included additional temperatures of 0 and 5 °C, which Walton and Henson were unable to obtain because of poor atmospheric control. The experiment was designed to obtain moisture absorption comparisons among five stalk positions, four temperatures, and three relative humidities replicated three times. The experimental design was set up as a split-plot with the split occurring among relative humidities. This design and the selected variables required the preparation of 180 test units (leaves). The selected variables were as follows:

Temperatures.....0, 5, 10, 15 °C
Relative Humidities.....55, 75, 85 %
Stalk Positions.....5 (X,C,CB,B,and T, from the
bottom to the top of the stalk respectively)
Replications.....3

The test units (samples) consisted of single tobacco leaves arbitrarily selected from each stalk position. The leaves from one stalk were conditioned in a 12% relative humidity environment while the leaves from another were being tested. The tests used leaves from a total of 36 stalks. The steps involved in collecting the absorption data were as follows:

1. Whole leaves were conditioned to a low initial moisture content.
2. Absorption data for the whole leaves were collected.
3. Plots of the moisture absorption curves were made.

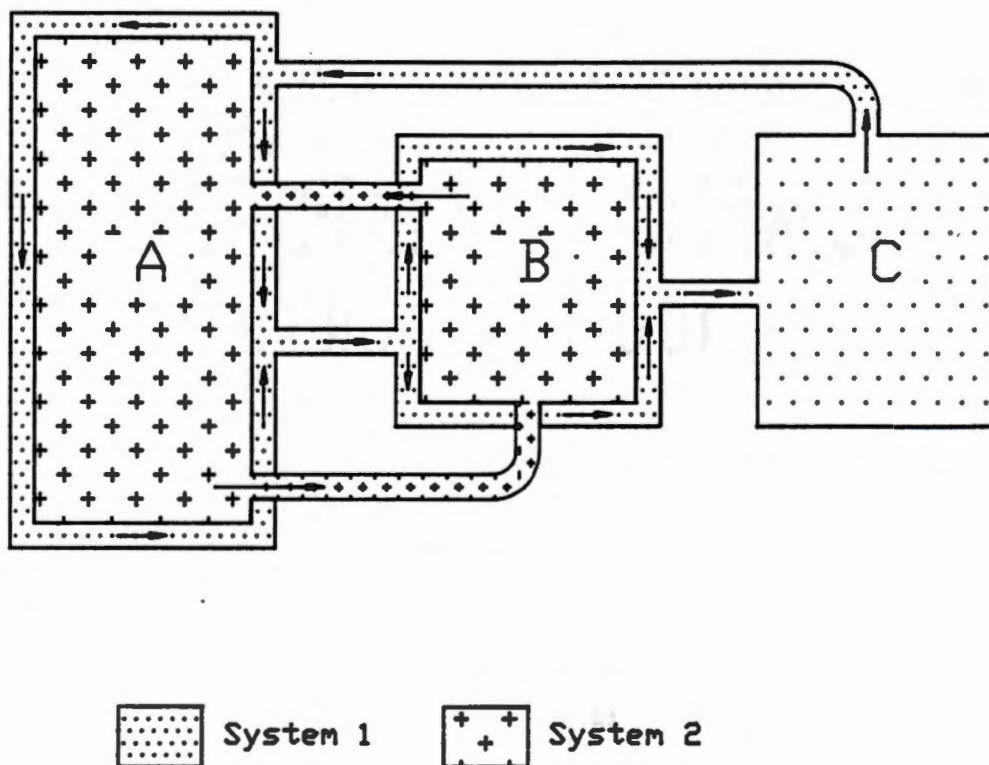
4. The exponential drying equation was fitted to the data by using the SAS procedure NLIN.
5. The calculated coefficients for all leaves were analyzed by using the SAS procedure ANOVA.

Equipment

The leaf preconditioning chamber consisted of a medium sized ice chest which was fitted with a shelf to keep the leaves above a saturated salt solution. The ice chest contained a one-inch-deep lithium chloride salt solution to hold the relative humidity to approximately 12%.

Figure 1 shows a drawing of the conditioning system built for the absorption tests. This system consisted of three separate units comprised of two closed atmospheric systems. The first closed system (Chamber C, Figure 1) used a 0.5-m by 0.5-m by 0.8-m freezer to circulate cold air around the other two units to maintain the desired temperature during a test, while the other closed system (Chambers A and B, Figure 1) included the leaf and salt chambers for controlling relative humidity.

The leaf chamber (Chamber A) was 1 m by 0.3 m by 0.3 m and had a removable, transparent door to allow easy access when loading leaves. The plexiglass door (Figure 2) had a 10-cm diameter hole cut into its center to permit access to the leaves for manual weighing. The hole was sealed between weighings. A small load cell (10-g maximum capacity) was mounted outside and above the leaf chamber with a small wire



CHAMBERS:

- A Leaf Conditioning Chamber
- B Salt Solution Chamber
- C Air Temperature Conditioning Chamber

Figure 1. Schematic Drawing of the Environmental Control System Used for the Burley Tobacco Absorption Tests.



Figure 2. Removable Plexiglass Door to the Environmental Chamber for the Absorption Tests of Burley Tobacco Leaves. The Sealed Hole, Which Permitted Access to the Leaves, Is Shown in the Center.

extending into the chamber. Leaves were placed onto a small hook at the base of the wire for weighing.

The salt chamber contained six pans which held the saturated salt solutions and provided roughly 1 square meter of surface area for contacting the conditioning air. The salts used for relative humidity control included MgNO_3 , NaCl , and KCl . Relative humidities produced by these salts were given by Rockland (1960) as:

Temperature	MgNO_3	NaCl	KCl
0	56	75.5	88.6
5	56	75.6	87.7
10	55	75.7	86.8
15	54	75.6	85.9

These precise relative humidities were not obtained, probably due to the temperature effect; however, the specific relative humidity remained nearly constant throughout each test.

A small fan provided air circulation between the leaf and salt chambers, with the air consecutively passing over each salt solution pan to reach the desired relative humidity. The freezer air circulated through a plenum (air space) which was situated on the outside walls of both the leaf and salt chambers. Silicon rubber sealed all joints and connections to avoid mixing of the moisture conditioned air and freezer air. An insulation cover with

an R-value of 11 was placed around all the chambers, and insulated 3.81-cm PVC piping transferred air between the chambers.

The system controlled well for all conditions after a modification to prevent icing of the freezer coils. An insulated, moisture resistant outer chamber was built over both the salt and leaf chambers to solve the frost problem. A small home air conditioner kept this outer chamber cooled to near 8 °C (Figure 3) and also lowered the vapor pressure substantially. This permitted very consistent control for periods as long as six days.

The data included temperatures in all chambers, relative humidity in the leaf chamber, and weight gain of the leaves. The experiment used two separate data acquisition systems. One system measured and recorded all temperature readings and also calculated relative humidity from wet-bulb and dry-bulb thermocouple readings. The other system converted voltage signals from the load cell and humidity probe into digital signals by using a 12 bit analog-to-digital conversion board. The load cell had a voltage output of 0-5 volts which corresponded to a weight range of 0-10 g (Figure 4). The weight measuring system had a combined sensitivity of 410 digital counts per gram. The humidity probe had a voltage output of 0-1 volt which corresponded to 0-100% RH (Figure 5). The probe manufacture claimed an accuracy of $\pm 2\%$ RH in the range of 0-80% and $\pm 3\%$



Figure 3. Air Conditioned Chamber Over the Leaf and Salt Chambers Used for the Absorption Tests of Burley Tobacco Leaves.



Figure 4. 10-g Load Cell Used to Measure the Progressive Weight Gain of the Burley Tobacco Leaves in the Absorption Tests.



Figure 5. Probe Used to Measure the Relative Humidity Within the Environmental Chamber for the Absorption Tests of Burley Tobacco Leaves.

in the range of 80-95%. An IBM personal computer, interfaced with the A/D board, accessed all the digital signals, recorded them on floppy discs, and created a hard copy. Data analysis involved importing the information into a spreadsheet software package where various graphs and tables were made.

Procedure

Leaves were carefully removed from the selected stalks according to five relative positions from bottom to top of the stalk. One leaf was selected from the 4-6 leaves of each position. The five leaves, one from each stalk position, were then placed in the preconditioning chamber containing the 12% relative humidity atmosphere. The chamber was sealed air-tight and allowed to set for at least 96 h to insure a close approach to equilibrium moisture content. The leaf testing system (Figure 1, page 39) was operated for 24 h before each test to insure a stable environment. Immediately before a test, the leaves were removed from the preconditioning chamber, weighed, and then placed in the leaf chamber. The leaf chamber was quickly sealed and the leaves were alternately weighed on the load cell. The weighing process involved opening the sealed hole, inserting an arm, and manually placing the leaves on the load cell. A data acquisition program was loaded in the personal computer just before weighing began. The program read the signals (sampling rate) at the rate of

approximately 80 per second and averaged them over a 5-s interval. This sampling rate was sufficient to dampen the single, erratic load cell readings caused by vibrations. Each leaf remained on the load cell for at least five weighing cycles. Weights obtained by the load cell were very close to those obtained with the electronic scale, thus, providing a check on the load cell calibration.

Weight readings were taken at close intervals on the first day, since moisture absorption is much faster in the beginning of the test. The intervals were widened on consecutive days with final readings taken at 5-6 days or when leaves showed no further weight gain in a 12-h period. The extended period allowed a close approach to the equilibrium moisture content for all tests.

At the end of a test, all leaves were removed and quickly weighed on the electronic scale. The leaves were then folded, placed in small paper bags and put in the convection oven at 100 °C for 24 h at which time a bone dry weight was obtained. These bone dry weights were used to calculate moisture contents from the weight data.

The data were imported into a spreadsheet format and the bone dry weights inserted into a formula which calculated the moisture contents for all leaves. Averages and standard deviations for both temperature and relative humidity data were also calculated. Plots were drawn for

the moisture absorption versus time along with plots of the temperature and relative humidity histories for all tests.

The character data (order) was also determined at the same time as the final weights. Leaves were physically handled and a subjective evaluation of the leaf character was recorded. The character was described by a numerical scale as follows:

- 0 Bone dry condition, lamina will not bend without breaking.
- 1 The lamina may slightly bend.
- 2 The lamina is supple, but the leaf veins are still brittle.
- 3 Both lamina and veins are supple, along with one-third to one-half of the midrib.
- 4 The full length of the midrib is pliable. The lamina is in high order. The leaf will unfold itself when crumpled up.
- 5 The leaf is in very high order (soggy). It will not unfold itself when crumpled up.

The data were fitted to the exponential moisture absorption equation (equation [5]) by the SAS procedure NLIN (SAS User's Guide, 1985). This procedure used the method of Marquardt which minimizes the sum of squares of the differences between observed and predicted values of moisture content through an iterative process. The "goodness of fit" of the exponential equation to the data was described by the standard error of regression. The standard error was calculated from the sum of squares also.

Three coefficients (B1, B2, and B3) were estimated by the NLIN procedure. B2 and B3 estimated the slope of the moisture absorption curve, while B1 estimated the curve asymptote (equilibrium moisture content).

The calculated coefficients from all NLIN evaluated tests were then entered into the SAS procedure ANOVA (Freund, 1981). This analysis was used to describe relationships among all environmental conditions for all tests. Trends in the data could be analyzed by this procedure.

2. MOISTURE DETERMINATION EXPERIMENT

The second experiment involved preliminary drying tests which recorded the weight loss over time and the temperature history over time of various burley samples dried in a hot-air-blast oven. These tests were used as a basis for determining drying times, particle sizes, and initial moisture contents for the main drying experiment. Previous research has shown that rapid moisture removal from cured tobacco leaves can be obtained most effectively when the leaves are reduced to small particle sizes (Samejima and Yano, 1985). To verify this, whole leaves were dried in the hot-air-blast oven. Charring occurred before all moisture was removed, therefore, a test to determine an appropriate particle size range was made. The samples came from three

stalk positions, were ground to four different particle sizes, and preconditioned to four initial moisture contents.

The main drying experiment involved drying various burley samples at five different times based upon results from the preliminary experiments. The samples were from three stalk positions, ground to four particle sizes, and preconditioned to four initial moisture contents. All drying tests used a constant control temperature of 140 °C; however, the temperature entering the sample was approximately 120 °C.

An optimum particle size, drying time combination, was selected from the results. This optimum combination was used, in a further series of tests, to compare samples tested with the hot-air-blast oven to results from a conventional 24-h convection oven test. This comparison test used two initial moisture contents, five drying times, one particle size, and three stalk positions. A sample from each treatment combination was also dried in the convection oven for a direct comparison.

Preliminary Drying Tests

Methods and Materials. A preliminary drying experiment involving two methods for evaluating the moisture removal rate were made with the hot-air-blast oven. The first method measured the weight loss of various samples by periodically removing them from the oven and weighing them. The second method measured the temperature of the air

entering and leaving various samples to provide an indication of the extent of the isothermal period brought about by the heat of vaporization.

The experimental designs for the preliminary tests were completely randomized to obtain the most accurate estimate of the variability in the data (Anderson and Mclean, 1974). The following levels of variables were selected for both preliminary drying tests:

Stalk positions.....	bottom, top
Conditioning Environments.....	58%, 76%, 88% RH
Nominal Particle sizes.....	1, 3, 6, 25 mm
Replications.....	3

This selection of variables required the preparation of 72 samples. The data for the weight loss tests were analyzed by the SAS procedure NLIN (SAS User's Guide, 1985). Plots of the moisture loss were made for each test. The steps in the collection of the weight loss data were as follows:

1. Leaves were ground to the various particle sizes and placed into the conditioning chambers for a minimum of seven days.
2. A sample was obtained from one of the conditioning chambers.
3. The sample was placed in the preheated hot-air-blast oven.
4. The sample was removed and weighed once every minute for ten minutes then weights were taken at 12, 16, and 20 minutes.

The second method involved measuring the temperature histories of both the inlet and outlet of the sample pan as a sample was dried for 12 min. Plots of these histories were made. The steps involved in collecting this data were as follows:

1. Leaves were ground to the various particle sizes and placed in the conditioning chambers for a minimum of seven days.
2. A sample was obtained from one of the conditioning chambers.
3. The sample was placed in a specially constructed sample pan fitted with thermocouples at the inlet and exit.
4. The temperature histories of the inlet and exit were recorded on a two second interval over a 12 min period.

Equipment. Samples were conditioned in the sealed chambers containing the saturated salt solutions, as previously discussed (Figure 6). The relative humidity was measured by the humidity probe with an accuracy of $\pm 2\%$. The salts and their resultant relative humidities were:

LiCl.....	12%
MaNO3.....	58%
NaCl.....	76%
KCl.....	88%

The LiCl solution was not used in the preliminary drying tests but was used in later tests. The conditioning temperature was $26^{\circ}\text{C} \pm 3^{\circ}\text{C}$. The equilibrium relative



Figure 6. The Ice Chests Used as Conditioning Chambers to Obtain Initial Moisture Conditions for All Tests.

humidities obtained were temperature dependant, but for this experiment, the values above were considered to be constant.

Figure 7 shows the Wiley mill which was used to obtain the 1- and 3-mm samples. This mill ground the samples by using four rotating knives which closely pass four fixed knives. It had removable screens in sizes of from 1 to 6 mm in increments of 1 mm. The 2- and 6-mm screens were selected for this experiment. The samples were further sized by standard Tyler sieves. A paper cutter was used to cut the 6- and 25-mm samples. Several leaves were cut at once to reduce cutting time. Figure 8 illustrates the different particle sizes used in the experiment. All samples were placed in rigid plastic containers before conditioning. Holes were bored in the container lids to allow the conditioning air into the samples.

Weight loss of the samples was measured by an electronic scale which had an accuracy of ± 0.01 g (Figure 9). The sample pans were 500-mesh sieves. A 15-cm high plastic pail was used between the scale and the hot sample pan to reduce the heat effect on the scale reading.

The hot-air-blast oven was a "Moisture Teller" manufactured by the George Fisher Foundry, Detroit, Michigan (Figure 10). This oven directs a stream of air over heating coils which are thermostatically controlled and adjustable to give a variable outlet temperature. The heated air is

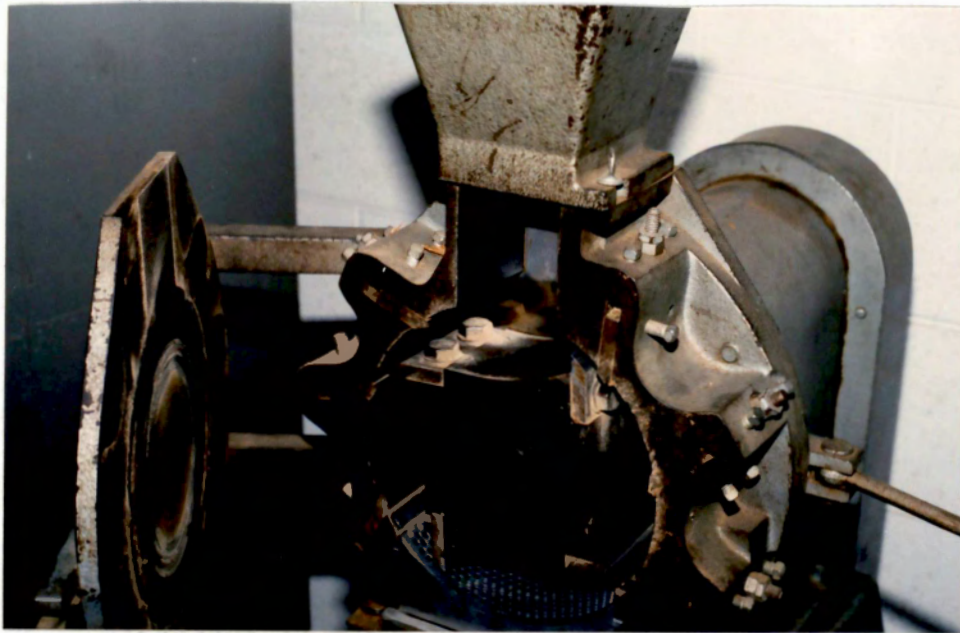


Figure 7. The Wiley Mill Used to Grind Burley Samples.



Figure 8. The Four Particle Sizes Used In the Hot-Air-Blast Drying Experiments.



Figure 9. Electronic Scales.

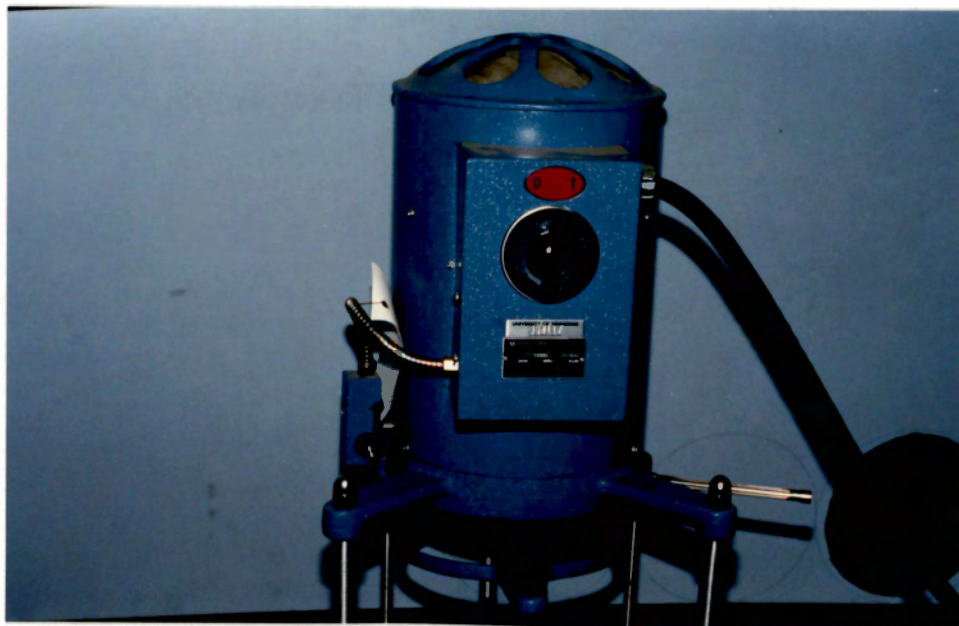


Figure 10. "Moisture Teller" Hot-Air-Blast Oven.

then directed through the sample and exits at the bottom of the 500-mesh screen (Figure 11). The temperature data were recorded on a Campbell Scientific data acquisition system (Figure 12).

Procedure. The leaves were separated into bottom and top stalk positions before being either ground or shredded. After the test samples were ground or shredded, they were randomly placed into the four conditioning chests and allowed to condition for a week. Samples were removed and weighed before each test. Initial weights were obtained by the same procedure for both weight loss and temperature history tests. The reduced size of the modified sample pan for the temperature tests did not permit a full 20-g sample for the larger, drier particle sizes.

The weight loss procedure involved placing the sample in the oven preheated to the 140 °C control temperature. The sample pan was removed, weighed and quickly returned to the oven at 1-min intervals for 10 min and then weighed at 12, 16, and 20 min. The data were manually recorded and later used to calculate moisture contents.

The temperature history procedure involved continuous drying and recording of the inlet and exit temperature histories of the samples during a 12-min drying period. One sample pan was fitted with a 5-cm diameter sample holder (Figure 13). The holder was situated in the center of the sample pan with the wire mesh outside the holder sealed to

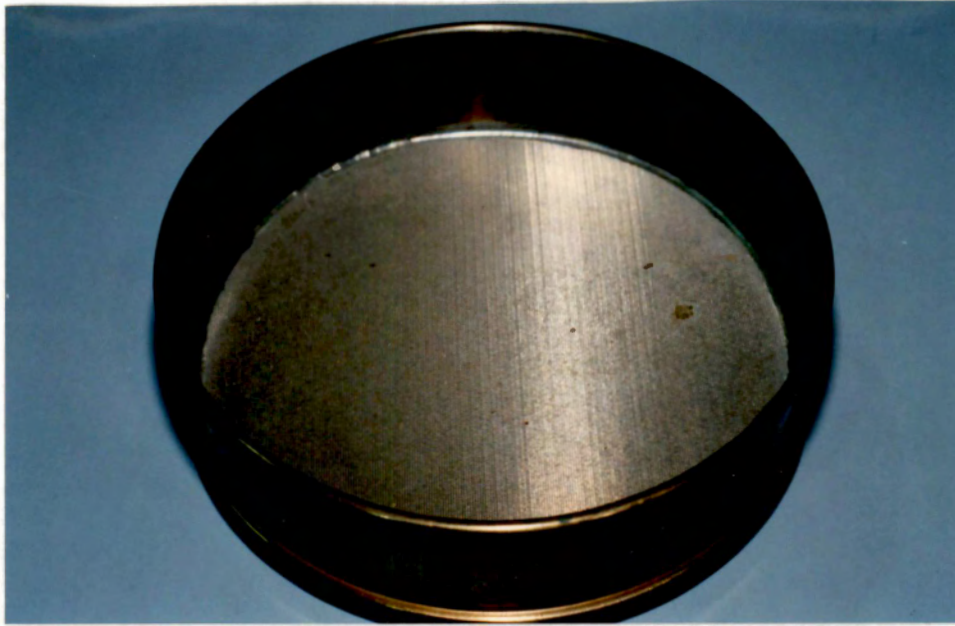


Figure 11. 500-Mesh-Screen Sample Pan Used in the Hot-Air-Blast Oven.



Figure 12. The Campbell Data Acquisition System.

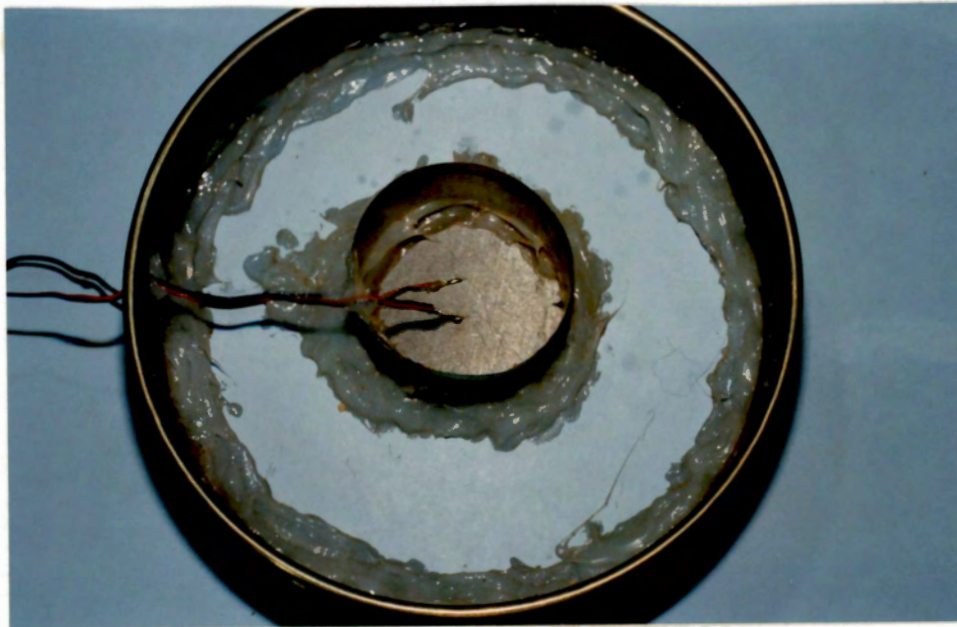


Figure 13. Modified Sample Pan Used in the Temperature History Tests.

insure that all air passed through the holder. One thermocouple was placed at the top and center of the holder at the sample surface to measure inlet temperatures, while a second thermocouple was placed at the bottom and near the wire mesh.

The sample was poured into the preheated sample holder. The Campbell Scientific data logger measured and recorded both inlet and exit temperatures on a 2-s interval over a 12-min drying period giving a total of 360 data points for each test. All data were stored on magnetic cassette tape and later downloaded to a personal computer and stored on floppy discs.

Main Drying Experiment

Methods and Materials. The experimental design for the main drying experiment was set up as a completely randomized fractional factorial design. The following levels of variables were selected for the experiment:

Nominal Particle sizes.....1, 3, 6, 25 mm
Stalk positions.....3 (bottom, middle, top)
Conditioning Environments.....12, 58, 76, 88% RH.
Drying times.....3, 5, 7, 9, 11 min

One replication of all treatment combinations required 240 samples. To reduce the size of the experiment for the time consuming tests, a design was selected which permitted a reduction to 120 randomly selected samples to give

information in one-half of all cells. This design required using the SAS procedure GLM (SAS User,s Guide, 1985) for analyzing the data since some cells were missing. The leaves came from three stalk positions (bottom, middle, top). Enough leaves were removed from each position to give a 20-g sample. Some stalks did not provide 20 g for each position, thus, a sample might contain tobacco from two or more stalks.

The method of collecting moisture content data was similar to the standard procedure used with a conventional convection oven. However, the hot-air-blast oven allowed a much quicker determination of the moisture loss. The steps in the collection of moisture content data were as follows:

1. Leaves were arbitrarily obtained from a specific stalk position and reduced to the various specified particle sizes.
2. Samples were conditioned to the various initial moisture contents.
3. Samples were randomly chosen, weighed, and then dried in the hot-air-blast oven.
4. Weights were manually obtained and recorded after each randomly selected drying time had elapsed.
5. The data were statistically analyzed by an analysis of variance procedure.

Equipment. The same equipment was used to obtain data for this experiment as was for the preliminary drying tests. The Campbell data acquisition system, however, was not used since only weight data were obtained. The drying oven

heating coil exit temperature was constant at 140 °C; however, the actual temperature entering the sample was only 120 °C.

Procedure. All samples were placed into the four conditioning chambers according to the randomized order specified by the design, after completing the grinding or shredding. The chambers contained different numbers and/or order of samples since the design was a fractional.

The samples were removed in the specified order after conditioning for a week. A 20-g sample was weighed, placed in the drying pan, and then in the preheated hot-air-blast oven and dried for the specified time. The sample and pan were then removed and quickly weighed for a determination of the dry weight. Moisture contents were calculated for all tests on a dry basis. The statistical analysis was used to evaluate the variance among all parameters and to estimate the optimum operating conditions for the hot-air-blast oven.

Comparison With The Convection Oven

The optimum operating conditions for the hot-air-blast oven were used in a very limited comparison test with the 24-h convection oven. The procedure used the two ovens with three stalk positions, five times, one particle size, and two initial moisture contents.

Methods and Materials. The experimental design for the oven comparison experiment was completely randomized and

included a 24-h convection oven sample for every sample dried in the hot-air-blast oven. Regression Analysis was used to analyze all the data. The following levels of variables were selected for the experiment:

Nominal Particle size.....3 mm

Stalk positions.....3 (bottom, middle, top)

Conditioning Environments.....76, 88% RH.

Drying times.(hot-air-blast)...7, 9, 11, 13, 15 min

The steps in the collection of moisture content data were as follows:

1. Leaves were arbitrarily obtained from a specific stalk position and reduced to the various specified particle sizes.
2. Samples were conditioned to the various initial moisture contents.
3. Samples were randomly chosen, weighed, and then dried in either the hot-air-blast or the convection oven.
4. Weights were manually obtained and recorded after each randomly selected drying time had elapsed.
5. The data were statistically analyzed by a regression analysis.

Equipment. The same equipment was used to obtain data for this experiment as was for the preliminary drying tests. The Campbell data acquisition system, however, was not used since only weight data were obtained. The drying oven heating coil exit temperature was constant at 140 °C; however; the actual temperature entering the sample was only

120 °C. The temperature in the convection oven was 100 °C $\pm$ 1 °C.

Procedure. All samples were placed into the four conditioning chambers according to the randomized order specified by the design. The samples were removed in the specified order after conditioning for a week. A 20-g sample was weighed, placed in the drying pan, and then in the preheated hot-air-blast oven and dried for the specified time. The sample and pan were then removed and quickly weighed for a determination of the dry weight. A sample with the same treatment combination was weighed, placed in the convection oven at 100 °C, and dried for 24 h. Moisture contents were calculated for all tests on a dry basis. A regression analysis procedure was used to evaluate the relationship between the two ovens.

CHAPTER IV

RESULTS AND DISCUSSION

1. MOISTURE ABSORPTION EXPERIMENT

Control of the environmental conditions obtained in the leaf chamber within any individual replication (except as otherwise noted) was within ± 1 °C and $\pm 2\%$ RH as shown by the typical control curves of Figures 14 and 15. The actual temperature held within the ± 1 °C of the desired for all replications. The actual relative humidities varied from desired as shown in Table 1. The variation among replications within an individual temperature-relative humidity combination stayed within 4% except for 0 °C, 85% RH. The average relative humidity for each temperature-relative humidity combination was within 2% of the desired except for three of the 55% RH combinations and the 15 °C, 85% RH combination.

Tables A-1 through A-12 (Appendix A) show the predicted values of the coefficients of the exponential equation (equation [5]) from the non-linear regression analysis, along with the observed values for all tests. Model F-values for all tests were very high, signifying a very good fit of the exponential equation to the data. Table 2 shows the standard errors of regression along with observed and predicted moisture contents averaged over all replications and stalk positions for each environmental

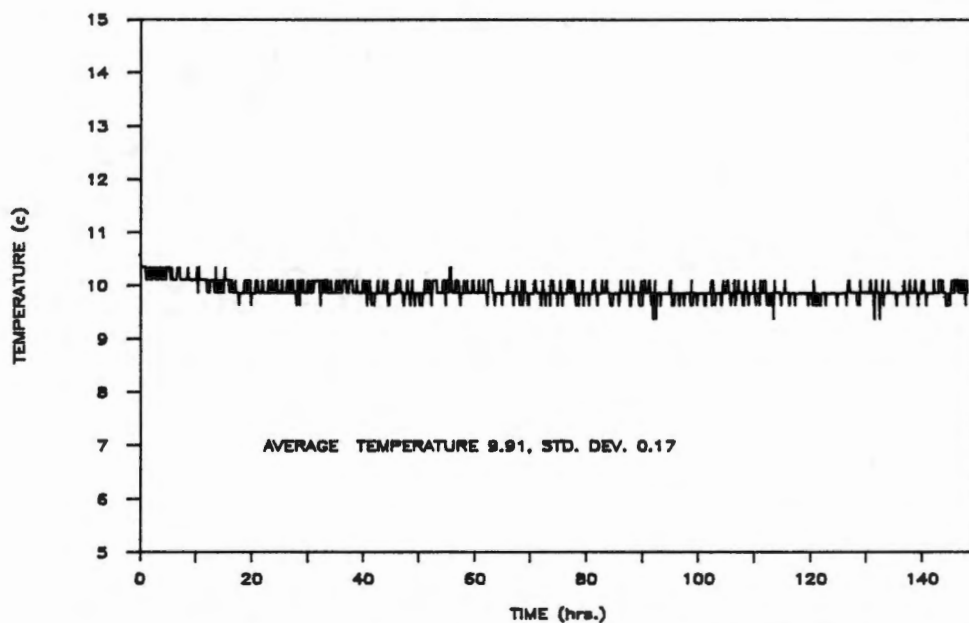


Figure 14. Example of the Temperature Control Obtained During One Test of Moisture Absorption in the Burley Tobacco Leaf at 10 °C, 85% RH.

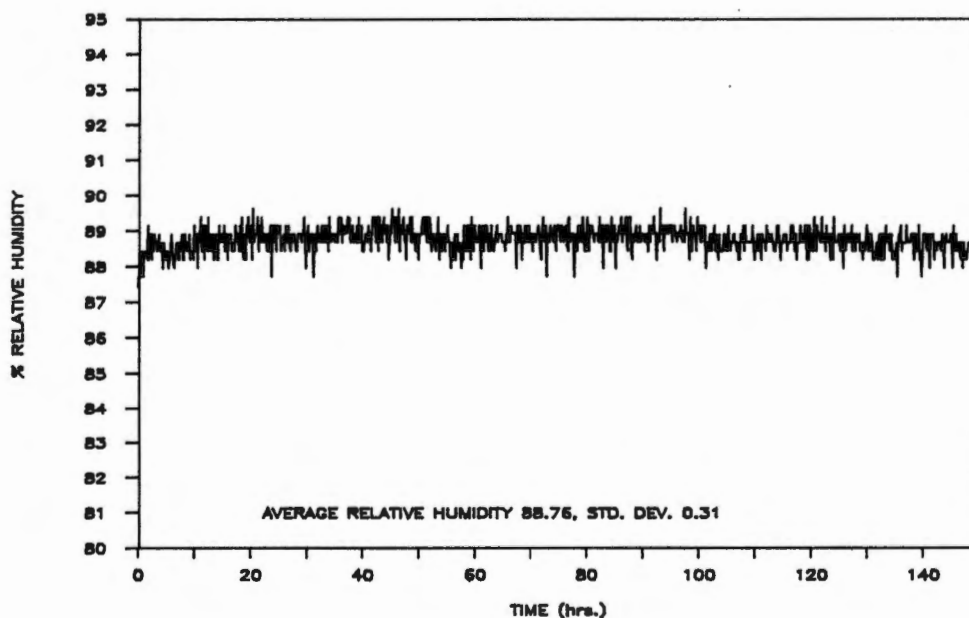


Figure 15. Example of the Relative Humidity Control Obtained During One Test of Moisture Absorption in the Burley Tobacco Leaf at 10 °C, 85% RH.

Table 1. Actual Relative Humidities Obtained in the Moisture Absorption Tests for All the Tested Environmental Conditions.

Desired Relative Humidity	Temperature (°C)	<u>Actual Measured Relative Humidities</u>			
		<u>Replications</u>			<u>Average</u>
		<u>1</u>	<u>2</u>	<u>3</u>	
85%	15	89.0	89.0	88.5	88.8
	10	85.2	85.2	84.8	85.1
	5	87.2	86.4	86.4	86.7
	0	85.5	85.6	80.0	83.7
75%	15	75.2	74.7	74.7	74.9
	10	75.4	74.0	75.0	74.5
	5	72.0	72.0	75.0	73.0
	0	78.5	74.7	75.0	76.1
55%	15	55.3	55.3	59.0	56.5
	10	52.0	52.0	52.0	52.0
	5	53.0	52.3	50.0	51.8
	0	49.1	49.0	47.0	48.4

Table 2. Average Predicted and Observed Values of the Equilibrium Moisture Contents with the Standard Errors of Regression from the Exponential Moisture Absorption Equation.

Environmental Condition	Predicted Moisture	Observed Moisture	Standard Error (percent m.c.)
0 °C, 48.4% RH	12.70	12.79	0.204
5 °C, 51.8% RH	15.09	14.83	0.376
10 °C, 52.0% RH	15.22	15.28	0.261
15 °C, 56.5% RH	15.81	16.24	0.175
0 °C, 76.1% RH	28.87	27.87	0.314
5 °C, 73.0% RH	24.52	24.72	0.403
10 °C, 74.5% RH	25.33	25.47	0.255
15 °C, 74.9% RH	23.47	24.09	0.286
0 °C, 83.7% RH	36.15	36.05	0.369
5 °C, 86.7% RH	34.83	34.89	0.420
10 °C, 85.1% RH	37.55	37.58	0.372
15 °C, 88.8% RH	35.03	35.13	0.413

condition. The standard errors for the 10 and 15 °C temperatures for both the 75 and 85% RH tests were as good as or better than those obtained by Walton (1974) using his mathematically derived equations. Tables A-13 through A-15 (Appendix A) contain the standard errors for all 180 burley leaves.

From comparison of Table 2 with results of Walton (1974), it was concluded that the standard exponential equation was a sufficient model to describe moisture absorption in burley tobacco leaves at low temperatures. The close environmental control of the system was considered to enhance the good fit of the equation. A typical example of an absorption data curve plotted with the predicted curve is shown in Figure 16. Tables B-1 through B-36 (Appendix B) contain the raw data for all tests. These data were used to generate the moisture absorption curves (Figures A-1 through A-36, Appendix A) and were entered into the SAS procedure NLIN (SAS User's Guide, 1985) to estimate the coefficients for the exponential equation. All tests were near their equilibrium moisture contents by the end of the test period.

The greatest error introduced in each test occurred on the first day. Opening of the sealed hole during weighing caused a slight change in the environmental conditions. Since the first several hours of absorption are the most

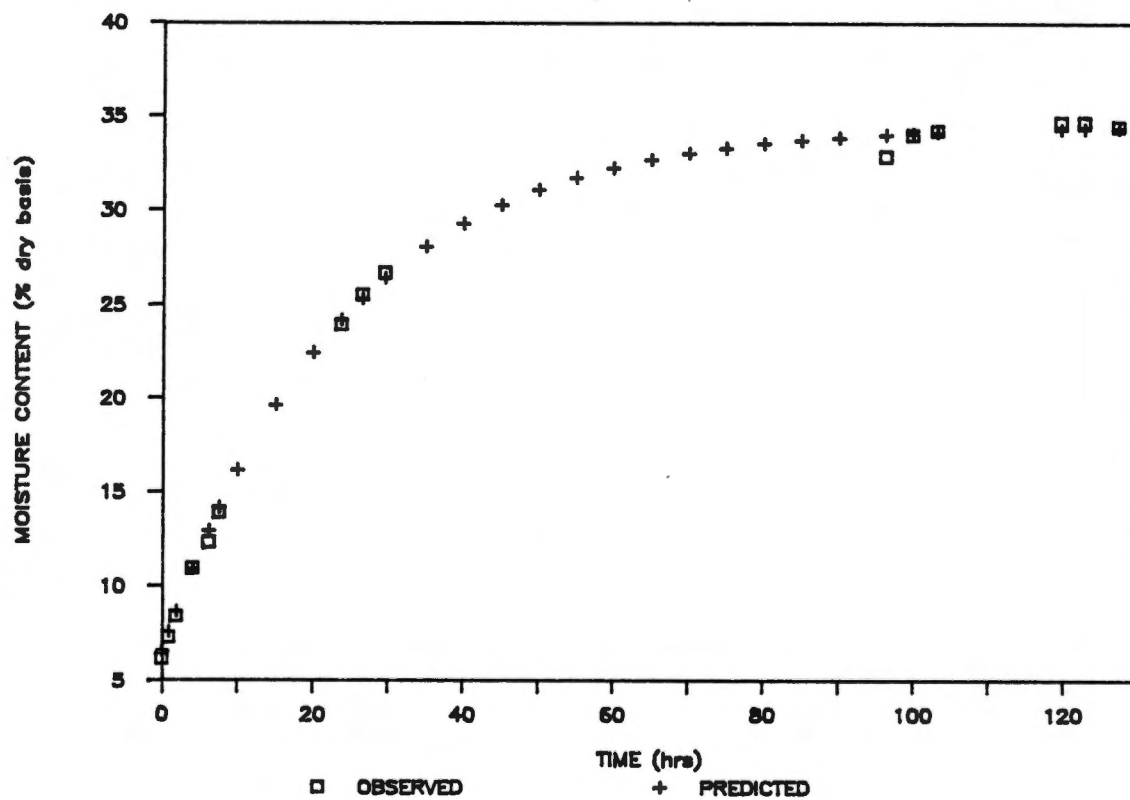


Figure 16. Observed and Predicted Moisture Absorption Curves for a Top Stalk, T, Leaf at 0 °C, 85% RH Plotted Over Time.

rapid and the leaves are weighed more often, the slight environmental change caused more error. A statistical method which determines if these errors are randomly distributed or if they contain systematic errors is the plot of the residuals. An optimum condition occurs when the errors are randomly distributed around the zero line (Kleinbaum, et al. 1988). An example plot of residuals for one of the tests (Figure 17) shows more variation at the beginning of the test. This pattern, which held for all tests, illustrates the resultant systematic error.

The average relative humidity value for the 0 °C, nominal 55% RH test was 48.4% with fluctuations between 43 and 53% for all three tests. The salt solutions were found to be saturated and the humidity probe was recalibrated, but the relative humidity remained low. The magnesium nitrate was either temperature sensitive at 0 °C or the cold plenum walls in the salt chamber were condensing some of the moisture faster than it could be replenished to the air from the salt solution surface. However, no condensate was apparent on the inside of the leaf chamber. The resultant moisture content for this combination (0 °C, nominal 55% RH) gave lower than expected moisture contents as may be seen in Table 2. The moisture content at this temperature was expected to be as high as that for the other temperatures at 55% relative humidity. This fact is further illustrated in the plot of predicted equilibrium

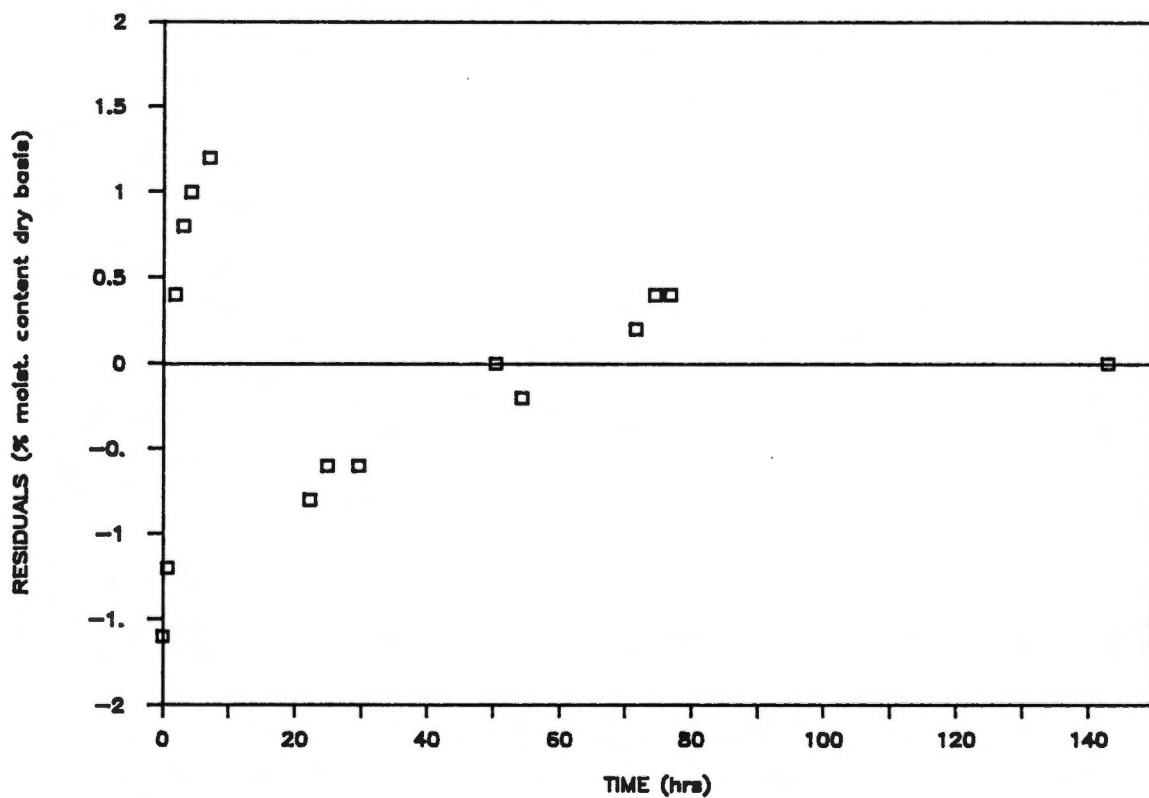


Figure 17. Residuals, An Indication of Systematic Errors, for a Moisture Absorption Test of a Mid Stalk (CB) Leaf at 15 C, 85% RH Plotted Over Time.

moisture content versus the actual relative humidities for all the temperatures (Figure 18). This plot represents the moisture isotherms for the environmental conditions tested.

The estimated coefficients for equation [5] were averaged over replications and stalk positions for all temperatures and relative humidities. These averages were then used to generate a family of curves for each relative humidity. The 85% RH test condition at 10 °C gave the highest average equilibrium moisture content which was 37% d.b., followed by the 0 °C at near 36%, with the 5 and 15 °C curves both showing near 34% d.b. (Figure 19). The 75% RH test condition at 0 °C gave the highest equilibrium moisture content which was 28% d.b., followed by the 10 °C at 25%, the 5 °C at 24%, and the 15 °C at 23% d.b. (Figure 20). The 55% RH test condition at 15 °C gave the highest equilibrium moisture content of 16% d.b., followed by the 10 and 5 °C at near 15%, and the 0 °C at 12% d.b. (Figure 21). The 0 °C curve shows the error introduced by the lowered relative humidity since this curve, theoretically, should produce the highest moisture content. The progression from high to low moisture contents should occur with the 0 °C to 15 °C temperatures respectively (Walton, 1974). The reversal of the 0 and 15 °C curves can be explained by the fact that the 0 °C average relative humidity was only 48.4% and the 15 °C was 56.5% as was seen in Table 1. Figure 22 combines the curves from Figures

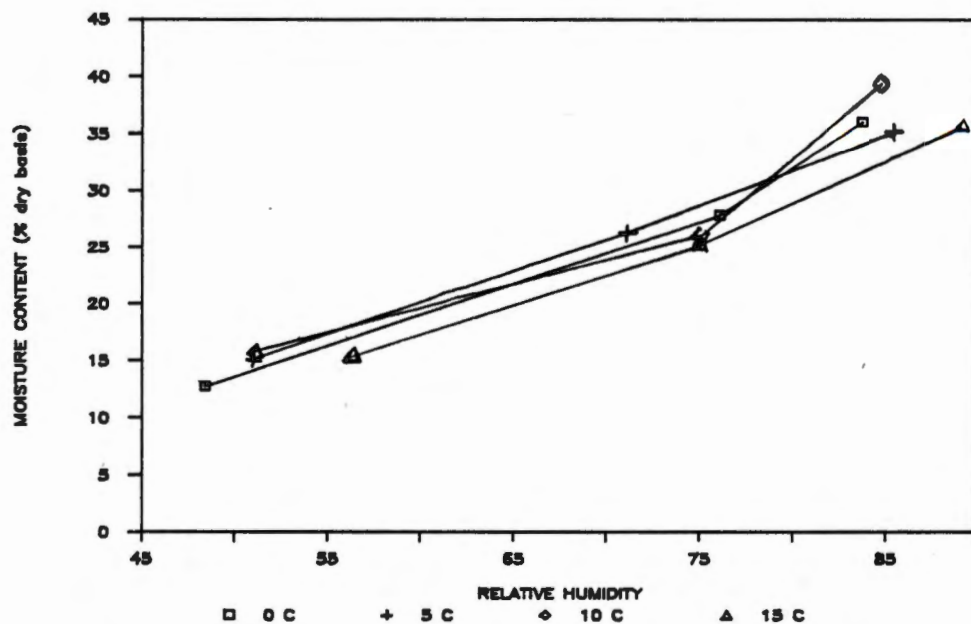


Figure 18. Plot of the Moisture Isotherms Generated from the Observed Data.

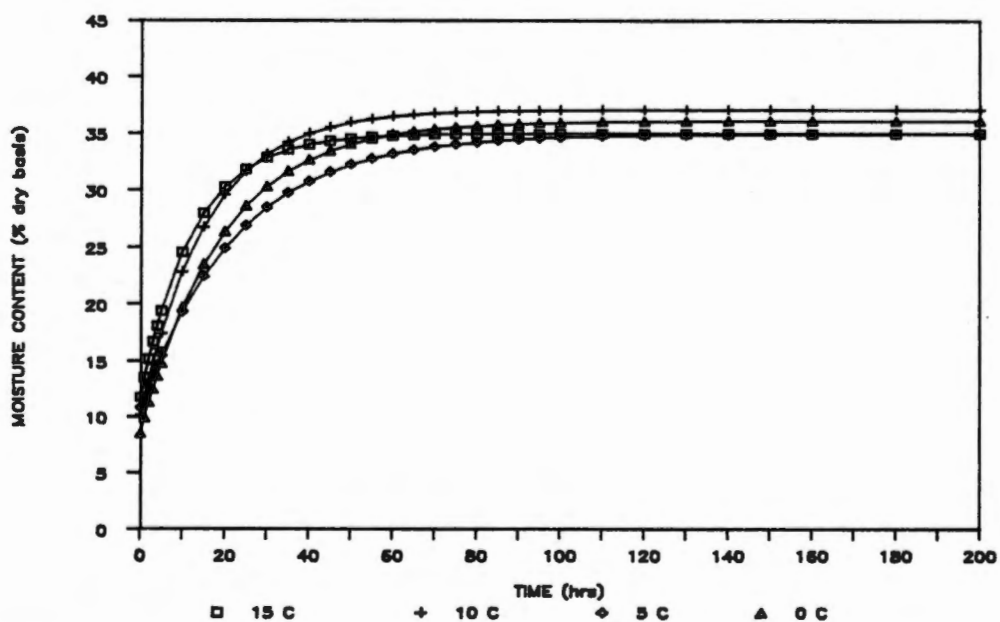


Figure 19. Predicted Absorption Curves, Using Equation [5], for All Temperatures at 85% RH Averaged Over Replications and Stalk Positions

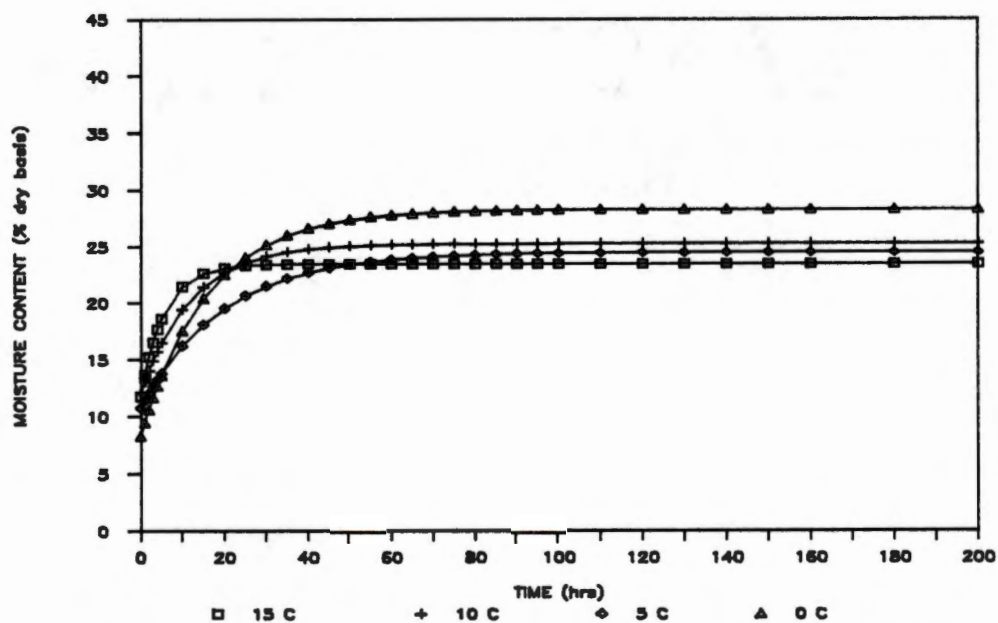


Figure 20. Predicted Absorption Curves, Using Equation [5], for All Temperatures at 75% RH Averaged Over Replications and Stalk Positions

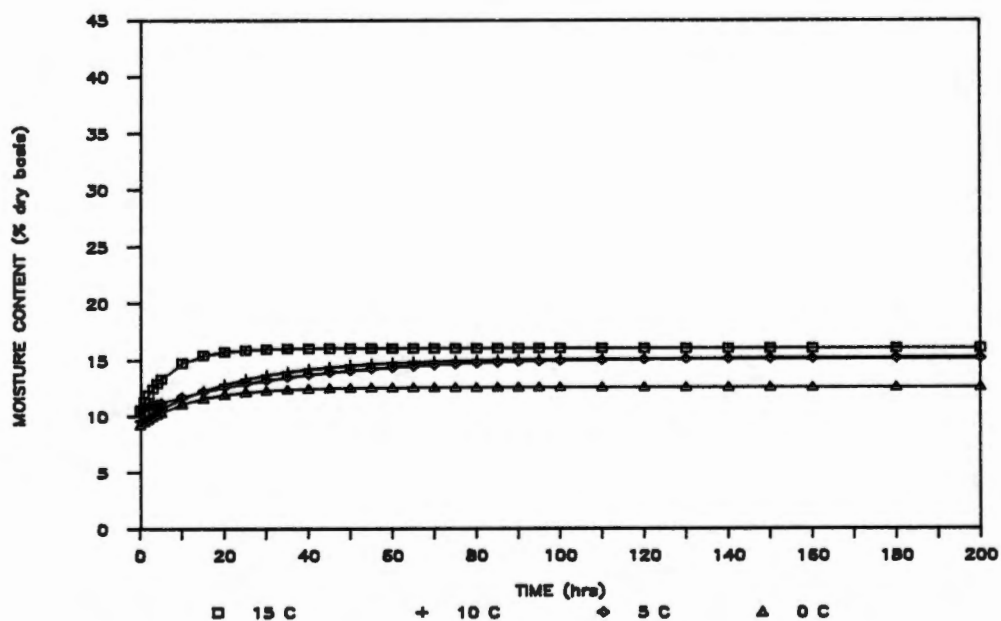


Figure 21. Predicted Absorption Curves, Using Equation [5], for All Temperatures at 55% RH Averaged Over Replications and Stalk Positions

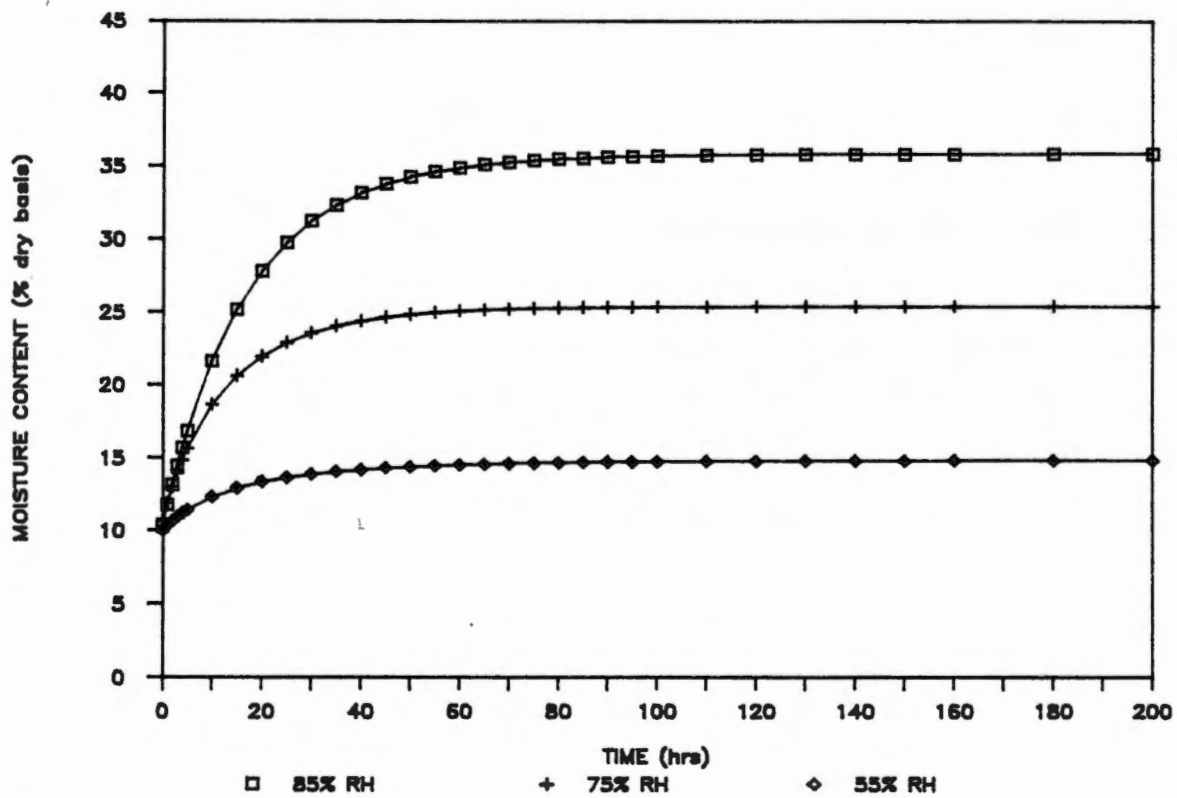


Figure 22. Curves of the Predicted Coefficients of Equation [5] Averaged Over Replications, Stalk Positions, and Temperatures for All the Relative Humidity Conditions.

19-21 to give average predicted curves for the three tested relative humidities. The 85% curve shows an equilibrium moisture content of near 35%, while the 75% curve shows around 24%, and the 55% curve shows near 14% d.b. If the 0 °C condition was corrected for the 55% RH condition, then this curve would probably show near 16% moisture content. All estimated coefficients were simultaneously analyzed by the SAS procedure GLM (SAS User's Guide, 1985) in the multivariate mode of calculation. Table 3 shows the results of the univariate analysis for the equilibrium moisture content coefficient, B3. Relative humidity, stalk position, and the relative humidity by temperature interaction all showed highly significant effects on equilibrium moisture. Relative humidity by stalk position interaction was significant at the 0.01 level of confidence and temperature was significant at the 0.05 level of confidence. The temperature by stalk position and the three way interactions were not significant. Table 4 presents the results of the univariate analysis for the equilibrium minus initial moisture coefficient, B2. The temperature and relative humidity by stalk position interaction for this coefficient became highly significant with the temperature by stalk position and the three way interactions remaining non-significant. Table 5 presents the results of the univariate analysis for the wetting constant (curve slope) coefficient, B3. The relative

Table 3. Results of the Univariate Analysis of Variance for the Dependant Coefficient, B1 of Equation [5], Which Represents the Equilibrium Moisture Content.

Source	DF	Type I SS ¹	F-Value	PR > F
RH	2	13278.92	1677.33	0.0
Temp	3	41.65	3.51	0.0175
RH*Temp	6	300.38	12.65	0.0001
Stalkpos	4	214.98	13.58	0.0001
RH*Stalkpos	8	88.52	2.80	0.0071
Temp*Stalkpos	12	80.19	1.69	0.0776
RH*Temp*Stalkpos	24	71.89	0.76	0.7822

¹Type I sum of squares used because of a balanced design.

Table 4. Results of the Univariate Analysis of Variance for the Dependant Coefficient, B2 of Equation [5], Which Represents Equilibrium Minus Initial Moisture Content.

Source	DF	Type I SS ¹	F-Value	PR > F
RH	2	12892.93	1620.22	0.0
Temp	3	313.13	26.23	0.0001
RH*Temp	6	541.36	22.68	0.0001
Stalkpos	4	382.85	24.06	0.0001
RH*Stalkpos	8	165.99	5.21	0.0001
Temp*Stalkpos	12	60.12	1.26	0.2517
RH*Temp*Stalkpos	24	102.76	1.08	0.3808

¹Type I sum of squares used because of a balanced design.

Table 5. Results of the Univariate Analysis of Variance for the Dependant Coefficient, B3 of Equation [5], Which Represents the Wetting Constant.

Source	DF	Type I SS ¹	F-Value	PR > F
RH	2	0.0319	5.81	0.0039
Temp	3	0.2198	26.71	0.0001
RH*Temp	6	0.0600	3.65	0.0023
Stalkpos	4	0.1967	17.93	0.0001
RH*Stalkpos	8	0.0059	0.27	0.9752
Temp*Stalkpos	12	0.0577	1.75	0.0637
RH*Temp*Stalkpos	24	0.0317	0.48	0.9797

¹Type I sum of squares used because of a balanced design.

humidity by stalk position interaction became non-significant with relative humidity and the relative humidity by temperature interaction less significant.

In comparing Tables 3 through 5, it is apparent that relative humidity affects the equilibrium moisture content much more than it does the slope of the curve (wetting constant). Conversely, temperature affects the slope of the curve much more than it does the equilibrium moisture content. Walton and Henson (1970) reached the same conclusion. Stalk position remained highly significant for both slope and moisture content. These results seem to indicate an inverse relationship between relative humidity and temperature when comparing them against their effects on slope and equilibrium moisture contents.

Table 6 shows how the subjective character evaluations compare to actual moisture contents. For the nominal 55% relative humidity condition the value ranges from 0.9 for the bottom leaf to 1.5 for the top leaf corresponding to moisture contents of from 14.3 to 15.8 percent respectively. These values would be somewhat higher if the error introduced by the 0 °C condition was accounted for. These leaves are all too dry for any form of market preparation. For the 75% RH condition, the values range from 2.6 for the second from bottom to 3.3 for the top of stalk corresponding to moisture contents of from 25 to 28 percent respectively. The 2.6 character value means the

Table 6. Comparison of the Subjective Leaf Character Evaluations to the Equilibrium Moisture Contents Averaged Over All Tested Temperatures for the Three Relative Humidity Conditions.

Relative Humidity	Leaf ¹ Position	Average Moisture Content	Average Character Value
55% ²	X	14.33	0.9
	C	14.30	1.0
	CB	14.36	1.2
	B	15.14	1.3
	T	15.80	1.5
75%	X	24.88	2.7
	C	24.88	2.6
	CB	25.43	2.7
	B	25.74	3.0
	T	26.79	3.3
85%	X	32.73	4.0
	C	34.95	4.2
	CB	36.88	4.3
	B	37.00	4.5
	T	38.01	4.5

¹The symbols X through T represent the positions on the stalk from bottom to top respectively.

²The actual relative humidities obtained for the three replications of this environmental condition ranged from 47 to 49%.

lamina and small veins are pliable, but the midrib is not. These leaves could not be worked by the conventional method of hand tying; however, they could be prepared by the "baling" method since supple midribs are not critical. The tip leaves had a value of 3.3 which means most of the midrib is supple. These leaves may possibly be worked conventionally, depending on whether the total midrib length is supple. The 75% RH condition seems to be the lowest point for market preparation when using the baling method. Conventional hand-tyed tobacco would need conditioning with a somewhat higher relative humidity. The 85% RH condition had values ranging from 4.0 for the bottom leaf to 4.5 for the top corresponding to 33 and 38 percent moisture contents respectively. These conditions favor the conventional hand-tying method since the midribs were very supple. The bottom stalk positions are at a low enough moisture content to allow safe storage until the sale, but the top two positions are at the borderline for safe keeping. Tobacco at this moisture content will begin to heat up when stored in bulk and may cause physical and chemical breakdown of the tobacco starting at the center of the bulk. Conventionally bulked tobacco is not as susceptible to heating as is baled tobacco because of lower densities in the bulk. Most tobacco at the sale warehouses is near this upper limit, especially when hand-tied and bulked in the conventional manner.

These averaged subjective character values may be used to obtain a rough estimate of the moisture content of burley tobacco. Values for conditions not tested in this experiment may be extrapolated between tabular values. Tables A-16 through A-18 (Appendix A) give the results of the evaluations for all temperatures and replications.

2. MOISTURE MEASUREMENT EXPERIMENT

Preliminary Drying Tests

Figures C-1 through C-3 (Appendix C) show the moisture loss curves obtained for the 1-mm particle size for the three initial moisture contents for the top stalk positions. The top position was similar to the other positions, therefore, only figures for the top position are presented. The curves were very similar over the various initial moisture contents with the moisture content reduced to near 2% after the first min for all 1-mm tests. The higher moisture content samples dried at a very high rate for the first min because of the influence of the small particle size, as was expected (Samejima and Yano ,1985).

Figures C-4 through C-6 (Appendix C) show the moisture loss curves obtained for the 3-mm particle size for the three initial moisture contents for the top stalk positions. These curves were very similar to the 1-mm curves because the particle size is still relatively small. The 1-mm particle size should have dried substantially

faster than the 3-mm size. The fact that this did not happen may have been caused by increased resistance to airflow caused by the closeness of the small 1-mm particles. The higher density of the small particles also affects moisture diffusion (Swetnam and Walton, 1984).

Figures C-7 through C-9 (Appendix C) show the moisture loss curves obtained for the 6-mm shreds for the three initial moisture contents for the top stalk positions. These curves are noticeably different than the 1-mm and 3-mm curves with the moisture contents after 1 min ranging from 4 to 6% d.b. corresponding to the initial moisture conditions obtained by the 55 to 85% RH environmental condition respectively. The 85% RH initial moisture conditioned samples now show a noticeable difference in moisture content after 1 min when compared to the 75 and 55% RH initial moisture conditioned samples. These differences in reduced drying rates show the dependance on the particle size.

Figures C-10 through C-12 (Appendix C) show the moisture loss curves for the 25-mm shred for the three initial moisture contents for the top stalk position. These curves show moisture contents after 1 min ranging from 4.5% for the 55% RH initial moisture condition to 7.5% for the 85% RH initial moisture condition. These curves further illustrate the difference in diffusion rates caused by the various particle sizes.

Figures C-13 through C-15 (Appendix C) show examples of temperature history curves for the 1-mm particle size over the three environmental conditions for the top stalk position. The top line is the temperature of the inlet for a 12-min drying period. The oven was preheated but the sample pan cooled somewhat during filling with a sample as evidenced by the beginning temperature. The inlet temperature reached a maximum in 1 min or less and was thermostatically controlled as evidenced by the ripple effect. The exit temperature had an immediate drop for the first few seconds caused by contacting the cool sample. The next level part of the curve is called the isothermal drying period (Chang and Johnson, 1971; Hassler, 1957 and 1959; Sykes and Johnson, 1969). The temperature approaches the wet-bulb and is stable during this period because of the effect of evaporative cooling. The small particle size allows the moisture diffusion rate to exceed the rate of drying with the excess moisture providing the cooling by absorbing the heat energy. As the diffusion rate decreases, the heat energy required for evaporation decreases and the temperature of the sample begins to rise as it accepts the heat energy of the inlet air. The S-shaped region of the curve represents the period from the beginning of the limited diffusion rate to the time when all free and physically bound moisture has been removed. For these curves, the exit temperature closely approached

the inlet temperature at approximately 250 s. This time should correspond to the point at which all moisture has been removed and any further drying will result in potential loss of dry matter and other volatiles.

Figures C-16 through C-18 (Appendix C) show examples of temperature history curves for the 3-mm particle size over the three environmental conditions for the top stalk position. These curves are very similar to the 1-mm curves except that the isothermal drying periods are less. This was expected since the larger particle size has a slower diffusion rate (Samejima and Yano, 1985). The exit and inlet temperatures closely approached each other at approximately the same time as did the 1-mm samples.

Figures C-19 through C-21 (Appendix C) show examples of temperature history curves for the 6-mm shreds over the three environmental conditions for the top stalk position. These curves show little or no isothermal period and no S-shape because of the much reduced diffusion rates. The sample began to heat almost immediately and the inlet and exit temperatures closely approached each other at 300 to 400 s. These samples are more subject to volatiles loss since the temperatures are elevated for a longer period.

Figures C-22 through C-24 (Appendix C) show examples of temperature history curves for the 25-mm shreds over the three environmental conditions for the top stalk position. These curves show an immediate exit temperature rise with

no S-shape and a lower slope than was apparent with the 6-mm curves. The much reduced diffusion rates caused a delay in the close approach of the exit and inlet curves to greater than 400 s. This particle size is much more susceptible to volatiles loss than was the 6 mm.

From these curves it was concluded that the 6- and 25-mm shreds dry too slowly with potentially high volatiles loss, while both the 1- and 3-mm particle sizes dry fast with less potential volatiles loss. The 3-mm particle size is more practical because it involves less grinding and has a smaller moisture loss in the process, thus, it allows a more accurate determination.

Table 7 shows subjectively determined values of the temperature history drying times averaged over the three replications. These data show an increase in drying times from small to large particle sizes in all cases except for the 55% RH initial moisture condition. The 25-mm shred at this condition dried nearly as quick as did the 1-mm size. This discrepancy possibly resulted from either error in subjectively selecting the drying times from the curves or from the restricted diffusion rates allowing the sample to approach the inlet temperature prematurely.

Main Drying Experiment

The analysis of variance results for the main drying experiment using the full model to test the selected particle sizes and drying times could not calculate the

Table 7. Estimated Drying Times from the Drying Temperature Curves Averaged Over Three Replications.

Environmental Condition	Stalk Position	Particle Size (mm)	Average Drying Time (s)
58% RH	Bottom	1	263.3
	Top	1	243.3
	Bottom	3	333.3
	Top	3	306.7
	Bottom	6	243.3
	Top	6	350.0
	Bottom	25	273.3
	Top	25	296.7
76% RH	Bottom	1	286.7
	Top	1	283.3
	Bottom	3	343.4
	Top	3	313.3
	Bottom	6	353.3
	Top	6	440.0
	Bottom	25	556.7
	Top	25	483.3
88% RH	Bottom	1	280.0
	Top	1	251.7
	Bottom	3	346.7
	Top	3	366.7
	Bottom	6	450.0
	Top	6	420.0
	Bottom	25	506.7
	Top	25	603.3

least-squares means for all the parameters because of the missing cells. Table 8 shows the analysis using a reduced model. This analysis calculated the least squares means for all the main effects and for the stalk position by moisture content interaction. Initial sample moisture contents had the most significant effect on the amount of moisture removed by the oven. The drying time was significant at the 0.0005 level and the sample particle size was significant at the 0.05 level. Table 9 shows the results of the estimated least squares means for the reduced model parameters. It was apparent that the 3-mm particle size showed the most moisture removed and the seven minute drying time was satisfactory. Figure 23 is a plot of the means of stalk position by initial moisture content interaction. At low initial moisture contents, tobacco from the bottom stalk position contains more moisture than does that from the top position. At high initial moisture contents, the opposite is true. This can be explained by the fact that tobacco from the top of the stalk contains more pore space, thus, allowing it to absorb more moisture in a wet environment and to desorb more moisture in the presence of a dry environment.

Oven Comparison Experiment

The limited oven comparison test only included one replication. The amount of variability explained by the

Table 8. Results of Analysis of Variance Using the Reduced Model for the Main Drying Experiment.

Source	DF	Type III SS	F-Value	Pr > F
Sta	2	13.879	7.15	0.0013
Part	3	8.405	2.88	0.0394
Moist	3	3712.508	1274.26	0.0
Time	4	22.590	5.82	0.0003
Sta*Moist	6	34.630	5.94	0.0001

Table 9. Estimated Least Squared Means for Evaluating
Moisture Content with the Hot-Air-Blast Oven.

Parameter	LS Mean Moisture % d.b.	STD ERR LS Mean Moisture % d.b.
Sta Pos		
Bottom	14.65	0.160
Middle	15.00	0.159
Top	15.51	0.160
Part Size (mm)		
1	15.11	0.186
3	15.33	0.184
6	15.18	0.185
25	14.59	0.188
Env (RH%)		
12	7.27	0.183
58	12.34	0.183
76	18.23	0.185
88	22.37	0.183
Time (min.)		
3	14.30	0.204
5	14.82	0.206
7	15.23	0.208
9	15.40	0.204
11	15.51	0.206

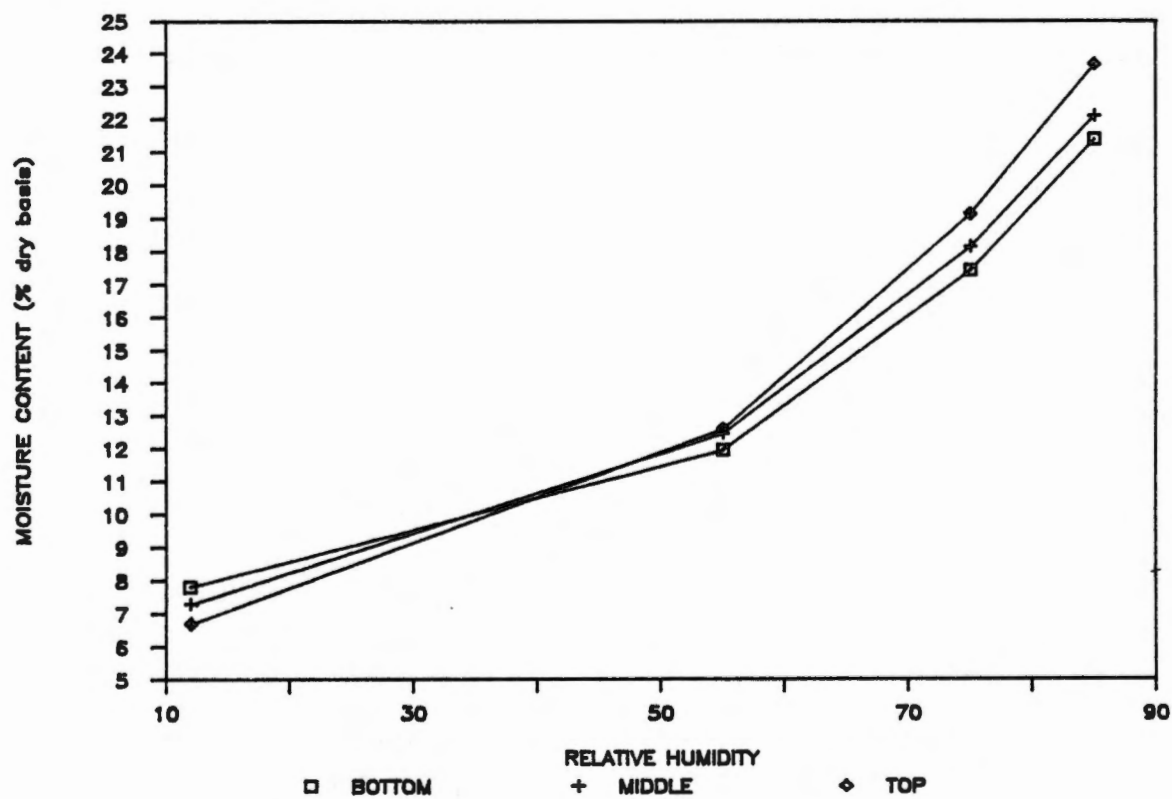


Figure 23. Least Squared Means of Stalk Position Versus Initial Moisture Content.

regression equation was only 73.6%. The limited regression equation was as follows:

$$\text{Conv} = 16.7 + 1.05(\text{Mtell}) - 1.03(\text{Time}) - 3.06(\text{Stalk})$$

Where:

Conv = The predicted convection oven moisture content, percent,

Mtell = The observed moisture content from the hot-air-blast oven, percent,

Time = Drying time for the hot-air-blast oven, min, and

Stalk = Stalk position of the sample, 1, 2, 3 represents from bottom to top of the stalk.

Figure 24 shows a regression equation using only the two ovens drawn with the scatter plot of the data. The R-Square for this reduced equation was still 63.8%, thus, showing the major effect of initial moisture content. A much more extensive test will be required to more correctly identify the specific relationship. These data indicate that, even though the hot-air-blast oven may not result in the exact value of moisture content, a relationship may be established which will permit a rapid drying technique for accurate moisture determination.

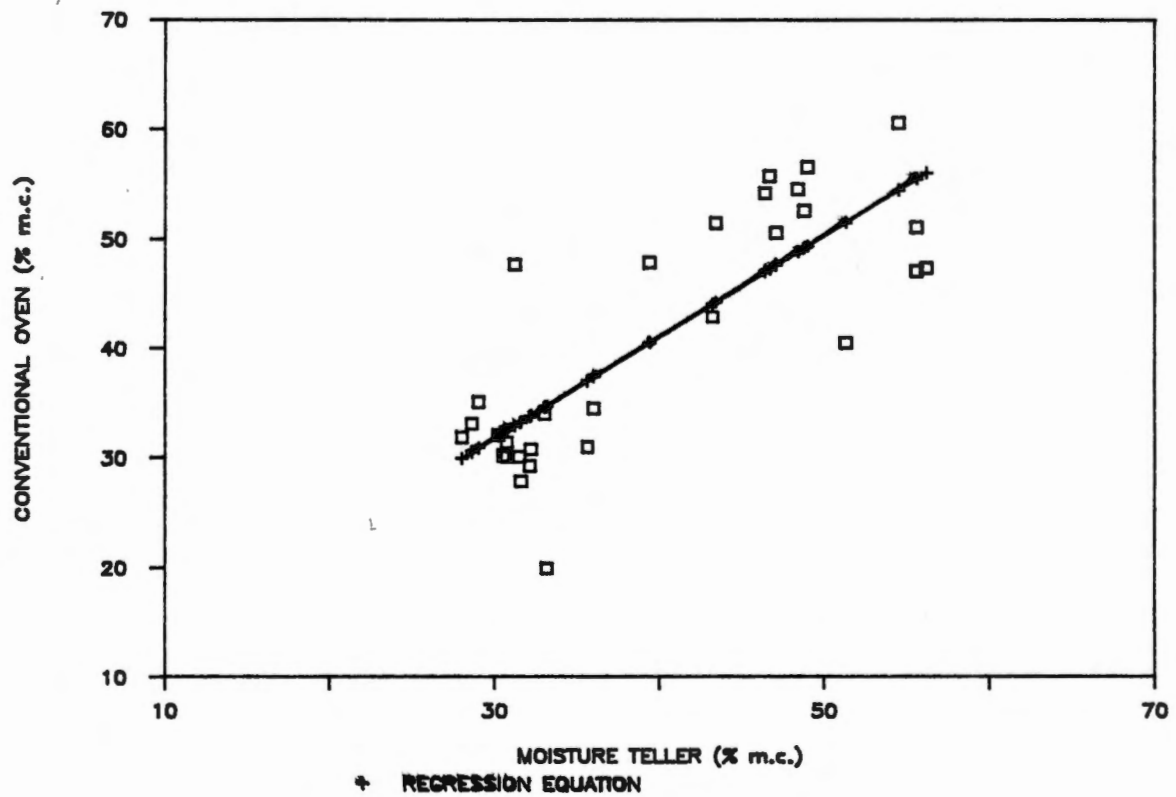


Figure 24. Scatter Plot and Regression Line from the Limited Comparison of the Hot-Air-Blast Oven to the Convection Oven.

CHAPTER V

SUMMARY AND CONCLUSIONS

1. MOISTURE ABSORPTION EXPERIMENT

Moisture absorption data for cured burley tobacco leaves were collected for environmental conditions experienced in the burley belt during October through December. These data were needed to adequately describe the physical nature of the burley leaf at these conditions. These data were successfully obtained for temperatures of 0, 5, 10, and 15 °C at 55, 75, and 85% relative humidities.

A review of the equations used to model moisture absorption in the burley tobacco leaf showed that the exponential equation gave accurate predictions in most cases. The accuracy depended upon the environmental control during a test. The model involved three parameters: equilibrium moisture content, a minor slope determinant with units of moisture content, and the major slope determinant with units of t^{-1} . Equilibrium moisture contents were assumed after a period of at least five days in an environment.

A test chamber was constructed for close control of the environment. A low initial moisture content was established by conditioning burley leaves in a 12% relative humidity environment for a minimum of five days. The individual leaf weights, weight gain, and resultant

moisture contents were obtained from a 10-g load cell interfaced through an A/D conversion board to a personal computer. The results showed that the exponential equation was adequate for describing moisture absorption curves.

The physical character (order) of each leaf was monitored during a test and a final determination made at equilibrium. This determination involved actually feeling the leaf and subjectively evaluating its character according to a predetermined scale. These data were used to describe the leaf handling properties for each condition tested. The subjective data were compared to the moisture content data and a character scale was established. Application of this character scale may provide a method for rough estimation of the moisture content at the market. A potential application may be in the estimate of initial moisture content for adjusting settings on rapid drying equipment to obtain a more accurate moisture determination. In addition, the character scale may be a step toward closer evaluation of a moisture content by both the farmer and the grader.

The following conclusions were formulated from this phase of the research:

1. The exponential moisture absorption equation used in this study accurately described moisture absorption of the cured burley leaf.
2. Relative humidity has a greater effect on the

equilibrium moisture than it does on the rate of absorption.

3. Temperature has a greater effect on the rate of absorption than it does on the equilibrium moisture content.
4. The subjectively determined character scale can estimate moisture content of burley tobacco at market environmental conditions.

2. MOISTURE MEASUREMENT EXPERIMENT

A hot-air-blast drying oven was selected for testing as a quick moisture determination method because of its ease of use, low cost, and safety. Preliminary tests identified the drying characteristics of ground and shredded tobacco samples. Drying rates by weight loss of the sample were obtained at a drying temperature of 120 °C for the 1- and 3-mm particles, and the 6- and 25-mm shreds conditioned to three initial moisture contents. A second test determined drying rates from the evaporative cooling as drying progressed. A high percentage of moisture in all tests was removed in less than 7 min for all treatment combinations.

These preliminary results were used in a more extensive test to establish optimum drying times and particle size for the most effective drying of a sample with a wide range of initial moisture contents. The

results indicated that initial moisture content had the greatest effect on the amount of moisture removed followed by the time of drying. Particle size was also a significant effect with most drying occurring with the 3-mm particle size. Even though drying times of 11 and 9 min removed more moisture, the 7-min test was acceptable.

A very limited comparison of the hot-air-blast to a standard convection oven indicated that a linear relationship exists between the two ovens. An in depth study will have to be done to fully explain the relationship between the two ovens. The results of this study may possibly be used to develop a calibration curve between the two ovens.

The following conclusions were formulated from this research with the hot-air-blast oven:

1. Sample particle size and initial moisture content have a definite effect on the drying times for burley samples.
2. An isothermal drying period exists with the 1- and 3-mm particle sizes.
3. Large particle sizes do not have an isothermal period because moisture loss is limited by the moisture diffusion rate.
4. The 3-mm particle size is optimum because it is small enough to allow fast moisture loss and still

large enough to allow adequate air flow through the sample.

5. At the temperature and airflow rates used in this experiment, a 7-min drying time adequately removes moisture from a sample.
6. Since initial moisture content affects the amount of moisture removed in a rapid drying, a close estimate of beginning moisture content is imperative.

3. RECOMMENDATIONS FOR FURTHER STUDY

An evaluation of the hot-air-blast oven as a tobacco moisture determination system should be conducted with samples of many different moisture contents, containing different types of tobacco grown at different locations from different years. This type evaluation should determine the error introduced from biological differences in the material. The use of the 3-mm particle size is recommended. It will also be important to establish the effect of varying both the drying temperature and airflow rate. A major problem which must also be addressed before a rapid method can be effectively be applied is that of obtaining a sample which adequately describes the market package.

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APPENDIXES

APPENDIX A.

Tables and Figures for the Moisture Absorption Experiment

Table A-1. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 15 °C and 85% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	13.0	21.87	0.111	34.87	10,909	12.28	35.41
C1	12.2	23.44	0.063	35.64	5,744	10.98	35.81
CB1	12.0	24.69	0.066	36.69	8,727	11.23	36.86
B1	12.0	24.50	0.063	36.50	4,940	10.74	36.65
T1	10.4	27.97	0.050	38.37	5,045	9.63	38.32
X2	14.6	15.00	0.249	29.60	40,655	13.96	28.93
C2	11.6	21.93	0.083	33.13	12,556	10.50	33.66
CB2	13.4	23.17	0.061	36.57	9,596	11.75	36.51
B2	9.8	24.88	0.059	34.68	14,980	8.58	34.89
T2	11.2	28.71	0.052	39.91	69,459	10.35	39.78
X3	11.6	19.14	0.105	30.74	11,076	10.20	31.08
C3	11.4	23.17	0.059	34.57	10,096	9.38	34.51
CB3	10.6	22.00	0.070	32.60	8,672	8.86	33.05
B3	10.8	23.91	0.060	34.71	15,293	9.42	34.98
T3	11.0	25.49	0.046	36.49	15,214	9.64	36.46

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-2. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 10 °C and 85% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	8.4	22.96	0.052	31.36	11,229	6.72	31.67
C1	9.4	27.79	0.052	37.19	9,622	7.64	37.90
CB1	8.4	30.03	0.039	38.42	12,398	7.00	38.49
B1	8.2	29.40	0.046	37.60	22,053	7.06	37.90
T1	8.0	31.31	0.033	39.31	20,960	6.52	39.29
X2	11.0	21.93	0.124	32.93	25,107	10.94	32.63
C2	12.8	22.88	0.071	35.68	6,959	11.52	36.25
CB2	8.2	32.27	0.048	40.47	14,860	7.59	40.71
B2	15.8	24.21	0.034	40.01	5,136	13.49	39.75
T2	9.2	32.11	0.035	41.31	14,224	8.19	41.24
X3	13.2	18.06	0.176	31.26	18,953	12.69	30.85
C3	11.8	24.14	0.096	29.86	10,661	10.57	35.54
CB3	10.6	29.31	0.058	39.91	8,183	9.04	39.29
B3	11.4	26.25	0.058	37.65	5,488	9.50	37.99
T3	11.6	32.60	0.042	44.20	16,807	10.38	44.24

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-3. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 5 °C and 85% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	14.4	19.99	0.089	34.39	23,926	13.93	35.01
C1	12.4	21.84	0.063	34.24	3,805	10.85	35.53
CB1	12.0	22.35	0.037	36.35	5,582	11.09	34.79
B1	12.0	28.47	0.022	40.47	6,807	10.97	39.12
T1	11.0	27.76	0.031	38.76	151,541	11.11	38.66
X2	13.6	20.31	0.067	33.91	11,767	12.78	34.08
C2	10.6	25.88	0.036	36.48	4,055	9.25	36.69
CB2	11.4	21.32	0.047	32.72	6,253	10.26	33.01
B2	9.6	25.75	0.036	35.35	9,688	8.66	35.51
T2	9.6	27.75	0.027	37.35	28,473	10.20	36.82
X3	10.4	24.64	0.064	35.04	24,320	10.06	34.64
C3	8.4	22.32	0.039	30.72	23,023	7.53	30.82
CB3	8.8	23.25	0.038	32.05	18,315	8.56	31.83
B3	10.0	22.70	0.036	32.70	6,534	8.61	33.52
T3	5.6	28.34	0.032	33.94	17,824	5.70	33.33

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-4. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 0 °C and 85% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	9.8	23.21	0.068	33.01	13,859	9.50	32.99
C1	9.4	26.65	0.064	36.05	19,422	8.69	35.86
CB1	9.8	35.71	0.031	45.51	4,804	8.12	46.50
B1	9.2	28.81	0.034	38.01	4,764	7.26	38.75
T1	8.2	31.19	0.039	39.39	5,182	7.39	39.67
X2	12.0	17.86	0.097	29.86	15,515	11.43	29.29
C2	8.8	25.99	0.040	34.79	8,760	7.41	34.76
CB2	8.0	29.97	0.030	37.97	8,573	7.09	37.84
B2	8.4	28.34	0.029	36.74	6,494	7.83	36.20
T2	7.8	27.78	0.019	35.58	17,179	7.32	33.80
X3	10.0	26.81	0.123	36.81	6,267	8.79	36.08
C3	7.4	24.11	0.069	31.51	14,032	6.99	32.10
CB3	6.0	27.71	0.043	33.71	54,335	5.11	33.71
B3	6.6	32.27	0.058	38.87	53,382	6.75	38.79
T3	6.6	27.92	0.042	34.52	24,834	6.16	34.47

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-5. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 15 °C and 75% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	15.8	11.92	0.268	27.72	22,960	15.62	27.67
C1	12.8	13.05	0.198	25.85	20,868	11.95	26.02
CB1	10.6	13.79	0.109	24.39	12,838	10.09	24.77
B1	11.2	13.99	0.125	25.19	9,658	10.32	25.70
T1	11.8	14.77	0.052	26.57	10,998	11.01	26.97
X2	11.0	11.04	0.457	22.02	16,147	10.85	22.22
C2	10.8	11.10	0.173	21.90	3,067	9.69	22.77
CB2	10.6	10.96	0.125	21.56	2,060	9.40	22.65
B2	11.2	11.92	0.150	23.12	2,905	10.13	24.05
T2	12.2	10.08	0.202	22.28	3,369	11.27	23.14
X3	12.2	9.11	0.266	21.31	11,763	11.44	21.81
C3	11.0	10.96	0.152	21.96	3,611	10.34	22.74
CB3	11.4	12.15	0.090	23.55	4,141	10.00	24.29
B3	10.8	11.89	0.103	22.69	2,436	9.98	23.75
T3	13.2	8.84	0.176	22.04	2,179	12.55	22.87

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-6. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 10 °C and 75% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	12.6	13.97	0.161	26.57	15,328	12.37	25.80
C1	11.6	14.02	0.098	25.62	19,628	10.60	25.18
CB1	12.0	13.22	0.096	25.22	9,932	10.57	25.30
B1	11.4	15.92	0.079	27.32	14,683	11.24	27.60
T1	12.0	15.96	0.041	27.96	23,450	10.91	27.88
X2	11.4	12.15	0.090	23.55	4,141	17.35	27.55
C2	14.2	9.10	0.108	23.30	5,419	12.67	23.22
CB2	14.0	9.91	0.090	23.91	4,245	12.68	24.12
B2	12.6	12.14	0.108	24.74	6,882	11.13	24.36
T2	11.0	15.95	0.088	26.95	5,617	10.18	26.55
X3	13.4	10.98	0.099	24.38	11,675	13.00	24.11
C3	11.8	12.89	0.060	24.69	10,179	10.99	24.55
CB3	10.2	13.96	0.039	24.16	7,148	9.48	24.17
B3	11.6	13.17	0.049	24.77	10,654	10.64	24.73
T3	11.4	15.45	0.028	26.85	29,117	11.05	26.99

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-7. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 5 °C and 75% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	11.4	11.99	0.071	23.39	16,273	11.22	23.72
C1	11.2	11.68	0.042	22.88	7,633	10.79	23.02
CB1	11.8	12.96	0.042	24.76	4,910	11.05	25.05
B1	9.8	15.30	0.028	25.10	3,201	9.94	25.05
T1	10.6	13.91	0.031	24.51	4,390	9.93	24.47
X2	12.2	9.27	0.063	21.47	1,979	12.54	21.32
C2	12.6	10.72	0.042	23.32	6,209	11.97	23.61
CB2	12.2	11.18	0.036	23.38	7,658	11.77	23.38
B2	12.0	10.96	0.042	22.96	7,729	11.51	23.02
T2	13.6	14.09	0.020	27.69	6,880	13.85	27.03
X3	10.6	13.69	0.128	24.29	7,405	9.89	23.95
C3	9.2	16.10	0.076	25.30	6,364	8.14	26.04
CB3	8.0	15.83	0.062	23.83	4,194	7.32	24.84
B3	8.2	18.44	0.047	26.64	3,562	7.57	27.68
T3	8.0	20.26	0.029	28.26	9,243	7.95	28.68

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-8. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 0 °C and 75% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	10.2	18.90	0.127	29.10	1,602	8.64	27.81
C1	7.8	20.13	0.117	27.93	5,213	8.06	27.26
CB1	7.8	23.79	0.095	31.59	5,727	7.87	30.82
B1	7.8	18.97	0.080	26.77	7,853	7.28	26.90
T1	7.8	20.72	0.072	28.52	26,117	7.93	28.43
X2	9.0	19.25	0.067	28.25	16,270	9.12	27.99
C2	9.0	20.72	0.027	29.72	39,257	8.70	28.92
CB2	8.4	22.25	0.033	30.65	9,086	7.84	29.97
B2	7.4	22.63	0.027	30.03	14,780	7.23	29.24
T2	6.8	25.73	0.031	32.53	21,177	6.65	31.77
X3	10.2	14.78	0.071	24.98	9,053	9.86	24.55
C3	9.2	16.17	0.059	25.37	27,806	8.79	25.17
CB3	8.0	17.72	0.053	25.72	13,163	7.44	25.82
B3	7.8	19.30	0.031	27.10	31,368	7.87	26.75
T3	7.4	19.48	0.035	26.88	16,129	7.47	26.69

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-9. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 15 °C and 55% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	13.0	3.23	0.157	16.23	6,471	12.28	16.45
C1	9.2	6.07	0.059	15.27	7,316	8.84	15.57
CB1	10.4	5.74	0.049	16.14	6,973	10.12	16.47
B1	10.6	6.07	0.057	16.67	7,383	9.93	16.94
T1	10.0	6.12	0.048	16.12	6,343	9.18	16.37
X2	11.0	4.93	0.141	15.93	7,428	10.65	16.19
C2	10.2	5.04	0.110	15.24	8,343	9.73	15.50
CB2	11.8	4.03	0.059	15.83	8,767	11.43	16.07
B2	9.8	5.00	0.067	14.80	8,807	9.39	14.99
T2	11.8	5.99	0.040	17.79	13,410	11.31	17.74
X3	11.0	6.12	0.542	17.12	12,547	10.66	16.75
C3	11.0	6.01	0.243	17.01	15,586	10.60	17.05
CB3	9.2	5.91	0.208	15.11	7,212	8.83	15.37
B3	10.4	6.05	0.198	16.45	10,122	9.76	16.50
T3	9.0	6.94	0.223	15.94	16,170	8.75	15.71

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-10. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 10 °C and 55% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	8.6	4.01	0.119	12.61	6,242	8.30	12.88
C1	7.8	5.82	0.067	13.62	3,027	7.40	14.04
CB1	8.0	5.16	0.048	13.16	4,478	7.18	13.21
B1	10.6	5.21	0.036	15.81	8,274	9.93	15.97
T1	10.8	6.73	0.046	17.53	7,201	10.84	17.17
X2	8.4	5.02	0.071	13.42	8,424	7.87	13.54
C2	9.6	4.23	0.056	13.83	4,880	8.89	14.16
CB2	10.0	5.06	0.060	15.06	6,193	9.58	15.42
B2	10.4	5.80	0.049	16.20	8,396	10.16	16.49
T2	10.8	6.38	0.024	17.18	12,462	10.47	17.21
X3	9.0	5.06	0.031	14.06	3,798	8.18	14.10
C3	10.0	5.51	0.025	15.51	8,082	9.28	15.46
CB3	10.2	7.10	0.019	17.30	4,140	9.62	16.95
B3	8.4	6.49	0.025	14.89	3,012	7.24	14.86
T3	11.2	6.93	0.019	18.13	9,193	10.63	17.72

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-11. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 5 °C and 55% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	13.4	3.02	0.142	16.42	8,100	12.85	16.82
C1	9.6	5.30	0.025	14.90	4,406	8.68	14.79
CB1	8.8	5.10	0.022	13.90	3,765	8.00	13.54
B1	10.0	5.23	0.018	15.23	4,931	9.09	14.79
T1	10.2	5.63	0.022	15.83	8,921	9.70	15.49
X2	11.2	3.11	0.024	14.31	4,639	10.26	14.18
C2	11.2	4.94	0.019	16.14	5,926	10.39	15.81
CB2	11.2	4.28	0.017	15.48	6,458	10.34	14.98
B2	11.6	4.45	0.016	16.05	5,347	10.57	15.59
T2	10.6	5.67	0.017	16.27	9,894	10.10	15.82
X3	11.4	3.65	0.026	15.05	4,571	9.90	14.98
C3	9.0	4.19	0.025	13.19	6,248	7.93	13.06
CB3	7.8	4.09	0.027	11.89	10,343	7.26	11.82
B3	10.2	5.04	0.020	15.24	8,076	9.30	15.08
T3	10.0	6.43	0.016	16.43	12,416	9.37	15.70

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-12. Initial and Final Moisture Contents from Three Replications of the Observed Data and from the Non-Linear Regression Analysis for Absorption Tests at 0 °C and Nominal 55% RH.

Leaf ¹ #	Coefficient Estimates (m.c.) ²				Model F-Value	Observed Data	
	B1-B2	B2	B3	B1		B1-B2	B1
X1	7.8	3.94	0.305	11.74	5,736	8.01	12.17
C1	7.6	4.03	0.207	11.63	1,882	6.30	12.21
CB1	9.8	3.10	0.036	12.90	7,411	9.13	12.98
B1	9.0	3.11	0.104	12.11	5,062	8.45	12.67
T1	10.6	2.26	0.032	12.86	7,103	9.70	12.98
X2	10.0	1.78	0.193	11.78	40,158	9.81	11.69
C2	9.4	2.71	0.051	12.11	10,705	9.04	12.30
CB2	10.0	3.07	0.029	13.07	7,538	9.37	13.06
B2	10.4	4.15	0.019	14.55	11,945	9.77	14.22
T2	11.2	3.04	0.029	14.24	18,000	10.82	14.23
X3	9.2	2.89	0.072	12.09	10,667	9.02	12.22
C3	8.0	3.58	0.026	11.58	20,118	7.90	11.66
CB3	9.2	3.36	0.024	12.56	15,846	8.60	12.47
B3	9.0	4.62	0.024	13.62	10,891	8.47	13.56
T3	8.4	5.20	0.019	13.60	15,185	8.13	13.41

¹The symbols X through T represent the stalk positions from bottom to top of the stalk respectively.

²B1-B2 represents the initial moisture content, B1 represents the equilibrium moisture content, B2 represents the equilibrium minus initial moisture content, and B3 represents the wetting constant in the exponential equation.

Table A-13. Standard Error of the Exponential Equation (Equation [5]) When Applied to Absorption Data of Burley Leaves at Various Temperatures and 85% RH.

Actual Environmental Condition	Stalk Position ¹	Standard Error (% moist. d.b.) <u>Replications</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
0 °C, 84% RH	X	0.261	0.209	0.383
	C	0.241	0.387	0.230
	CB	0.745	0.468	0.129
	B	0.599	0.537	0.144
	T	0.563	0.444	0.199
5 °C, 87% RH	X	0.207	0.340	0.223
	C	0.584	0.697	0.247
	CB	0.607	0.488	0.294
	B	0.874	0.432	0.514
	T	0.173	0.287	0.328
10 °C, 85% RH	X	0.308	0.169	0.187
	C	0.393	0.415	0.301
	CB	0.400	0.354	0.427
	B	0.274	0.729	0.499
	T	0.339	0.415	0.366
15 °C, 89% RH	X	0.443	0.121	0.254
	C	0.696	0.277	0.393
	CB	0.578	0.389	0.360
	B	0.763	0.291	0.313
	T	0.755	0.166	0.398

¹The symbols X through T represent stalk positions from bottom to top of the stalk respectively.

Table A-14. Standard Error of the Exponential Equation
(Equation [5]) When Applied to Absorption Data
of Burley Leaves at Various Temperatures and 75%
RH.

Actual Environmental Condition	Stalk Position ¹	Standard Error (% moist. d.b.)		
		<u>Replications</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
0 °C, 76% RH	X	0.686	0.223	0.266
	C	0.368	0.231	0.164
	CB	0.417	0.430	0.248
	B	0.322	0.370	0.213
	T	0.191	0.302	0.277
5 °C, 73% RH	X	0.194	0.550	0.244
	C	0.326	0.377	0.309
	CB	0.436	0.352	0.380
	B	0.593	0.330	0.498
	T	0.482	0.585	0.389
10 °C, 75% RH	X	0.184	0.343	0.200
	C	0.169	0.280	0.245
	CB	0.238	0.336	0.337
	B	0.220	0.257	0.261
	T	0.214	0.316	0.220
15 °C, 75% RH	X	0.154	0.143	0.169
	C	0.149	0.339	0.317
	CB	0.199	0.419	0.343
	B	0.228	0.370	0.417
	T	0.303	0.331	0.415

¹The symbols X through T represent stalk positions
from bottom to top of the stalk respectively.

Table A-15. Standard Error of the Exponential Equation
(Equation [5]) When Applied to Absorption Data
of Burley Leaves at Various Temperatures and 55%
RH.

Actual Environmental Condition	Stalk Position ¹	Standard Error (% moist. d.b.) <u>Replications</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
0 °C, 48% RH	X	0.133	0.053	0.119
	C	0.228	0.147	0.143
	CB	0.228	0.276	0.190
	B	0.162	0.410	0.237
	T	0.263	0.196	0.278
5 °C, 52% RH	X	0.182	0.385	0.391
	C	0.367	0.456	0.292
	CB	0.409	0.459	0.191
	B	0.461	0.569	0.374
	T	0.304	0.395	0.413
10 °C, 52% RH	X	0.149	0.143	0.318
	C	0.241	0.205	0.276
	CB	0.201	0.195	0.539
	B	0.202	0.185	0.416
	T	0.216	0.245	0.380
15 °C, 57% RH	X	0.199	0.179	0.130
	C	0.193	0.168	0.123
	CB	0.219	0.195	0.160
	B	0.213	0.172	0.149
	T	0.227	0.185	0.111

¹The symbols X through T represent stalk positions
from bottom to top of the stalk respectively.

Table A-16. The Subjective Leaf Character Evaluations for the Three Replications of All Temperatures Tested at 85% RH.

Actual Environmental Condition	Stalk Position ¹	Subjective Evaluated Data Replications		
		1	2	3
15 °C, 89% RH	X	4.0	4.0	4.0
	C	4.5	4.0	4.0
	CB	4.5	4.5	4.5
	B	4.5	4.5	4.5
	T	4.5	4.5	4.5
10 °C, 85% RH	X	4.0	4.0	4.0
	C	4.5	4.0	4.5
	CB	4.5	4.5	4.5
	B	4.5	4.5	4.5
	T	4.5	4.5	4.5
5 °C, 87% RH	X	4.0	4.0	4.0
	C	4.0	4.0	4.0
	CB	4.0	4.0	4.0
	B	4.5	4.0	4.5
	T	4.5	4.5	4.5
0 °C, 84% RH	X	4.0	4.0	4.0
	C	4.5	4.5	4.0
	CB	4.5	4.5	4.0
	B	4.5	4.5	4.5
	T	4.5	4.5	4.5

¹The symbols X through T represent stalk positions from bottom to top of the stalk respectively.

Table A-17. The Subjective Leaf Character Evaluations for the Three Replications of All Temperatures Tested at 75% RH.

Actual Environmental Condition	Stalk Position ¹	Subjective Evaluated Data Replications		
		1	2	3
15 °C, 75% RH	X	3.0	2.0	2.5
	C	2.5	2.5	2.5
	CB	2.5	2.5	2.5
	B	3.0	3.0	2.5
	T	3.5	3.0	2.5
10 °C, 75% RH	X	2.5	2.0	2.5
	C	2.5	2.0	2.0
	CB	2.5	2.5	2.5
	B	3.0	2.5	2.5
	T	3.5	3.0	3.0
5 °C, 73% RH	X	3.0	3.0	2.0
	C	3.0	2.5	2.5
	CB	3.0	2.5	2.5
	B	3.5	3.0	3.0
	T	4.0	3.5	3.0
0 °C, 76% RH	X	3.5	3.0	3.0
	C	3.5	3.0	3.0
	CB	3.0	3.0	3.5
	B	3.0	3.5	3.5
	T	3.0	4.0	4.0

¹The symbols X through T represent stalk positions from bottom to top of the stalk respectively.

Table A-18. The Subjective Leaf Character Evaluations for the Three Replications of All Temperatures Tested at 55% RH.

Actual Environmental Condition	Stalk Position ¹	Subjective Evaluated Data		
		<u>Replications</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
15 °C, 57% RH	X	1.0	1.0	1.0
	C	1.0	1.0	1.5
	CB	1.5	1.5	1.5
	B	1.5	1.5	1.5
	T	1.5	2.0	1.5
10 °C, 52% RH	X	1.0	1.0	1.0
	C	1.0	1.0	1.5
	CB	1.0	1.5	1.5
	B	1.5	1.5	1.5
	T	1.5	1.5	2.0
5 °C, 52% RH	X	1.5	1.0	1.0
	C	1.0	1.5	1.0
	CB	1.0	1.0	1.0
	B	1.0	1.5	1.5
	T	1.5	1.5	1.5
0 °C, 48% RH	X	0.5	0.5	0.5
	C	0.5	0.5	0.5
	CB	1.0	1.0	1.0
	B	1.0	1.0	1.0
	T	1.0	1.0	1.0

¹The symbols X through T represent stalk positions from bottom to top of the stalk respectively.

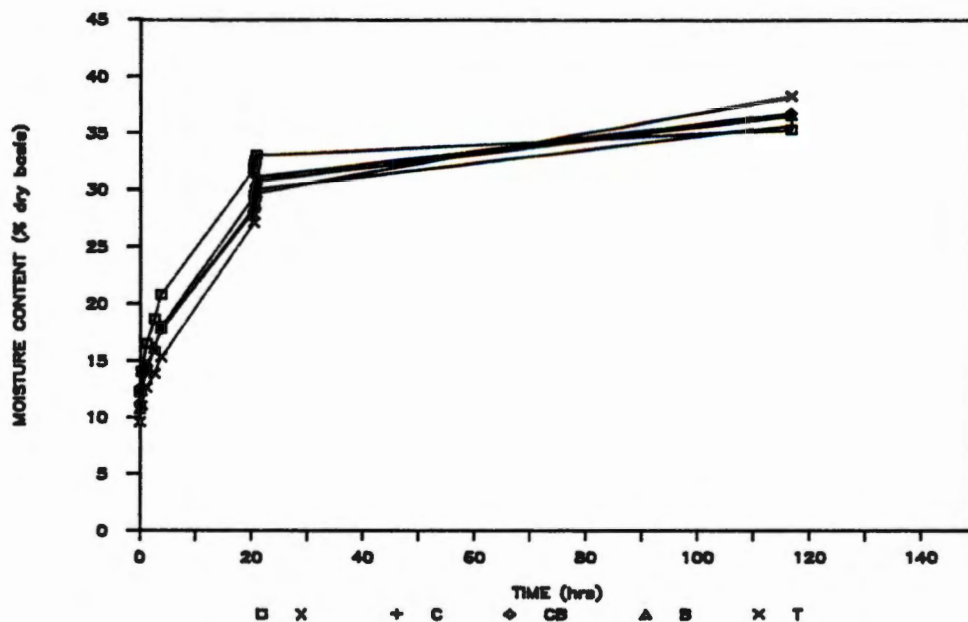


FIGURE A-1. Moisture Absorption Curves for the First Replication at 15 °C, 89% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

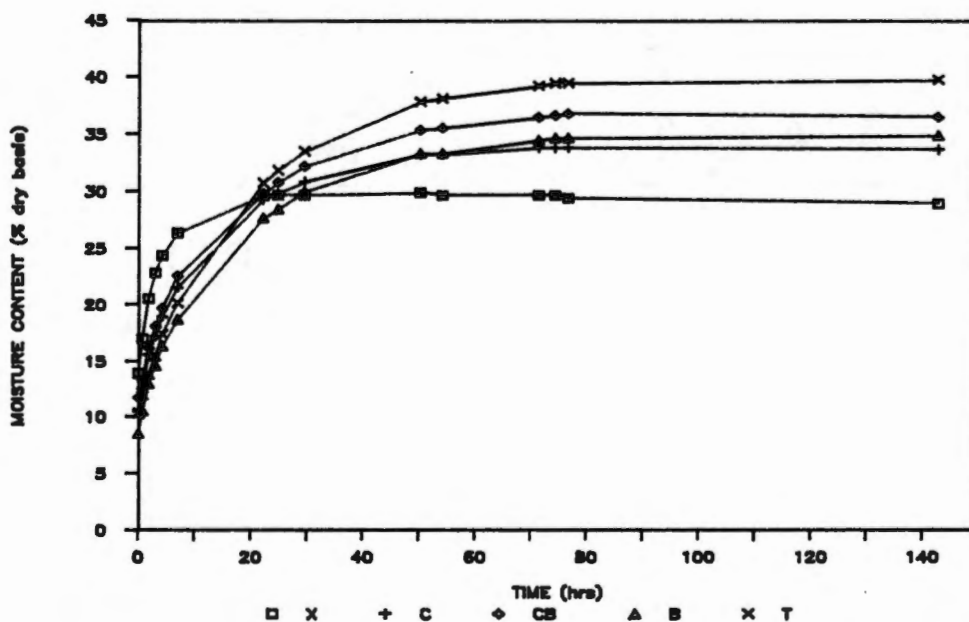


FIGURE A-2. Moisture Absorption Curves for the Second Replication at 15 °C, 88% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

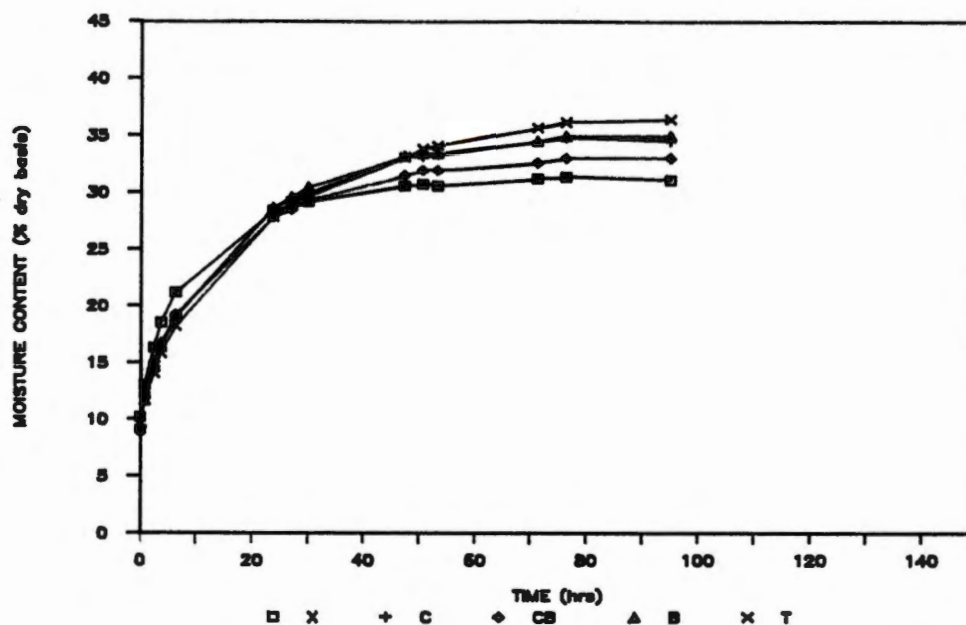


FIGURE A-3. Moisture Absorption Curves for the Third Replication at 15 °C, 89% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

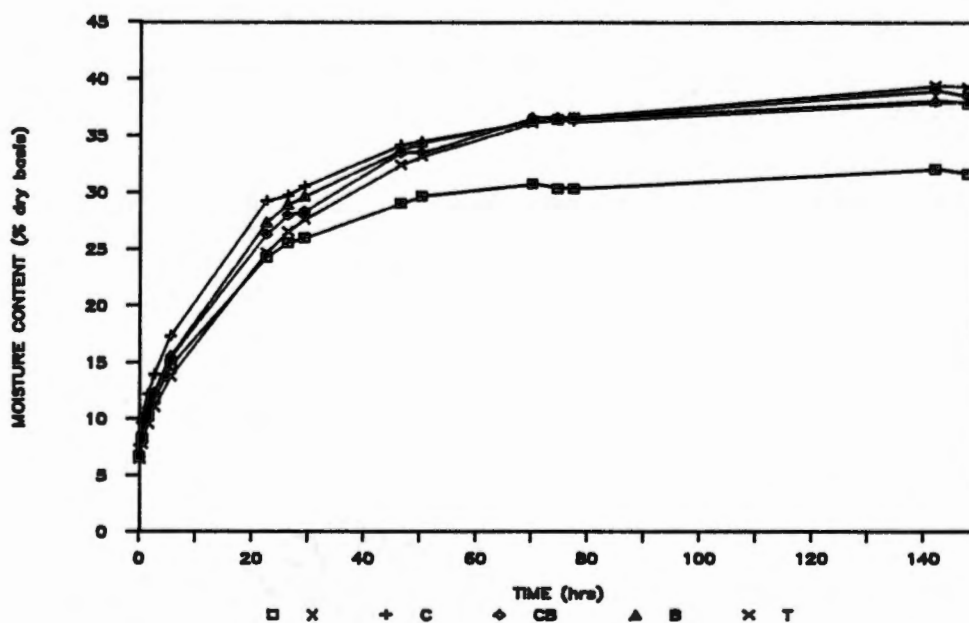


FIGURE A-4. Moisture Absorption Curves for the First Replication at 10 °C, 85% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

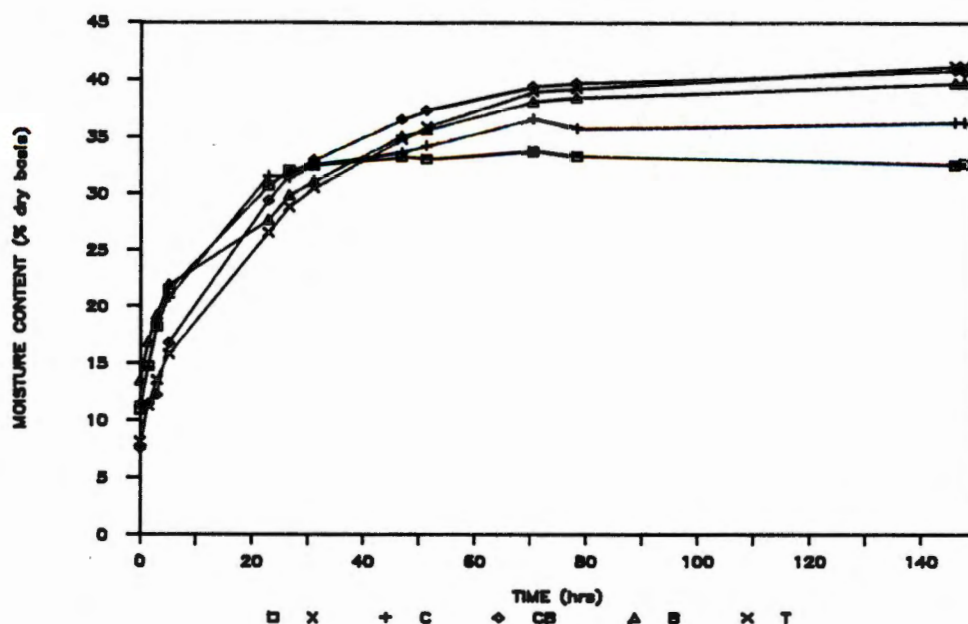


FIGURE A-5. Moisture Absorption Curves for the Second Replication at 10 °C, 85% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

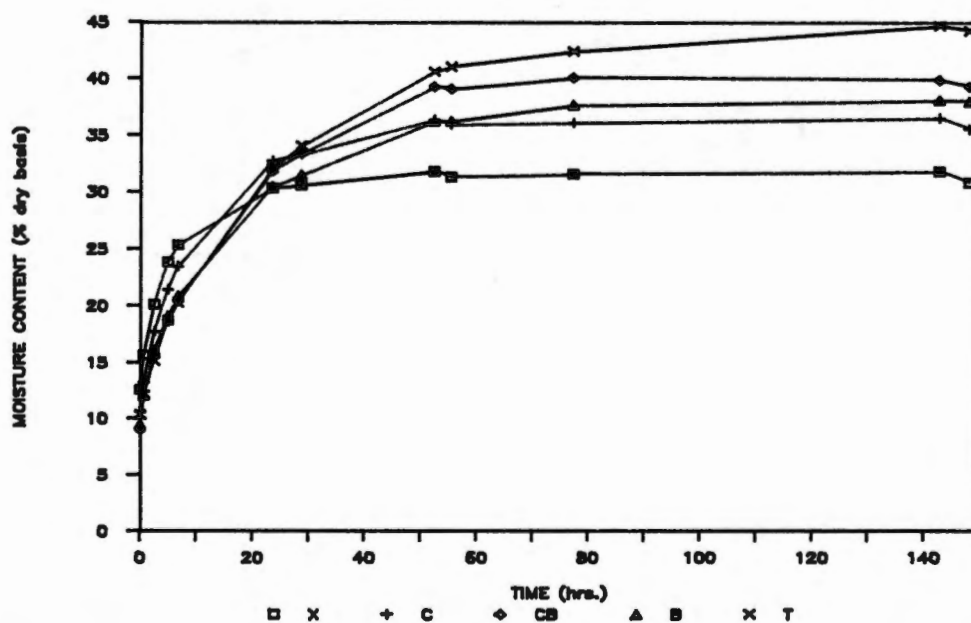


FIGURE A-6. Moisture Absorption Curves for the Third Replication at 10 °C, 85% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

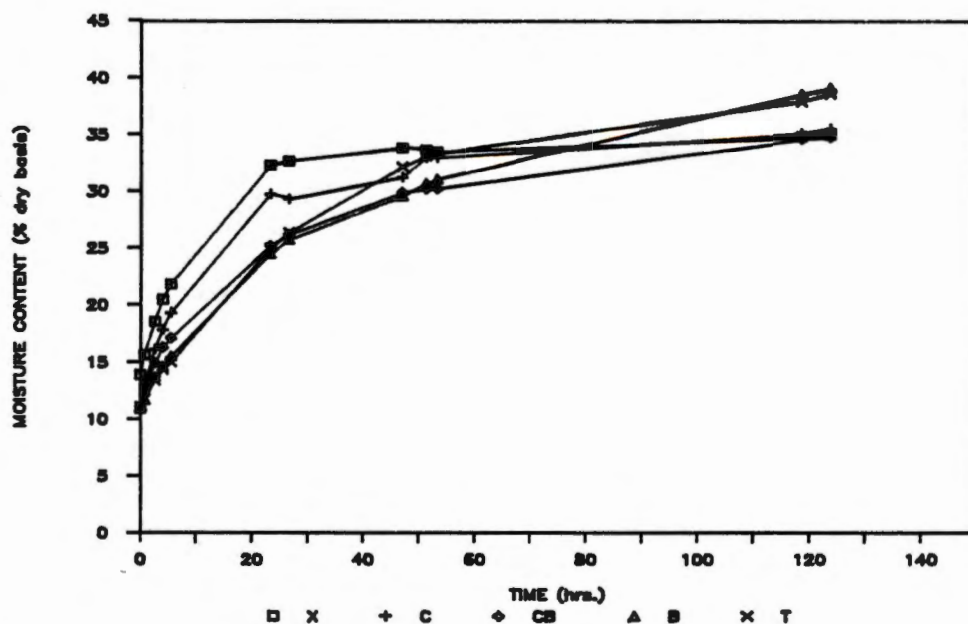


FIGURE A-7. Moisture Absorption Curves for the First Replication at 5 °C, 86% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

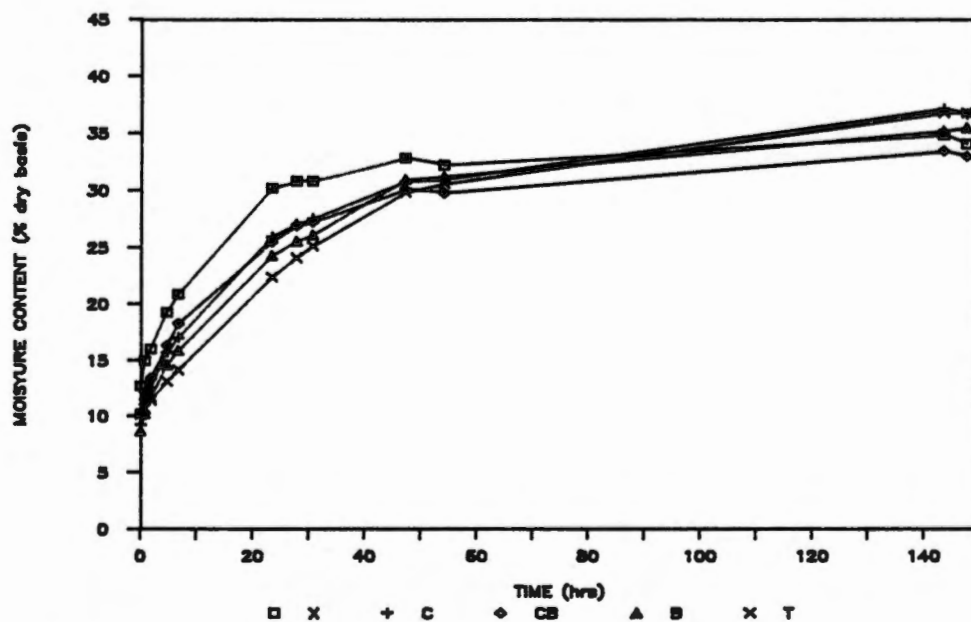


FIGURE A-8. Moisture Absorption Curves for the Second Replication at 5 °C, 86% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

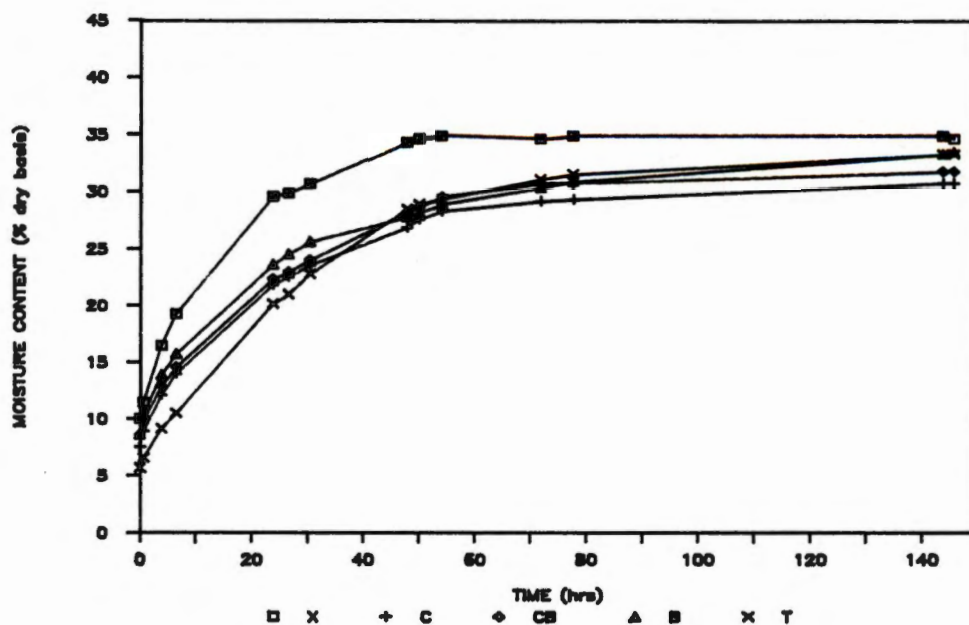


FIGURE A-9. Moisture Absorption Curves for the Third Replication at 5 °C, 87% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

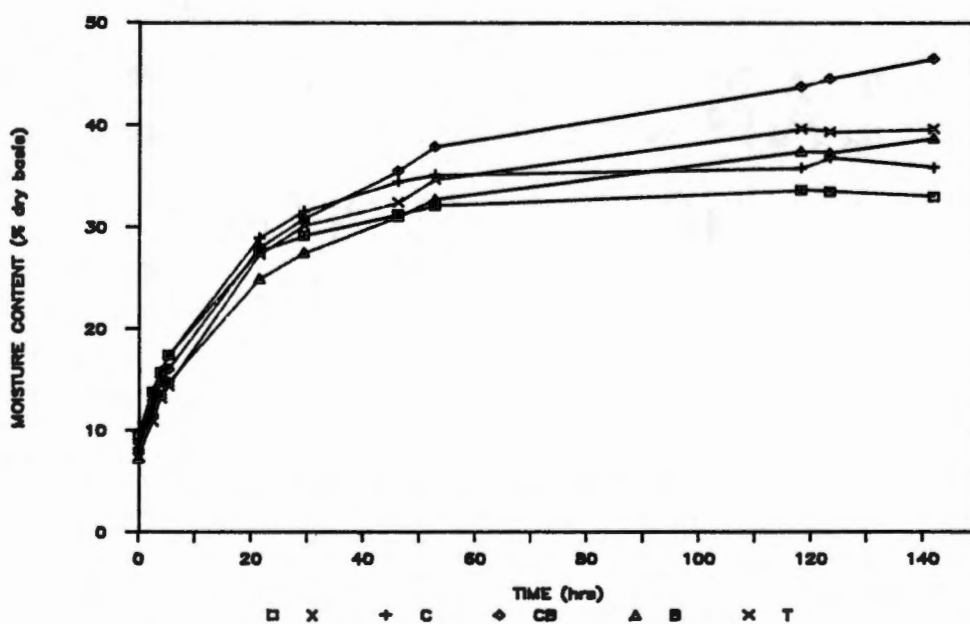


FIGURE A-10. Moisture Absorption Curves for the First Replication at 0 °C, 80% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

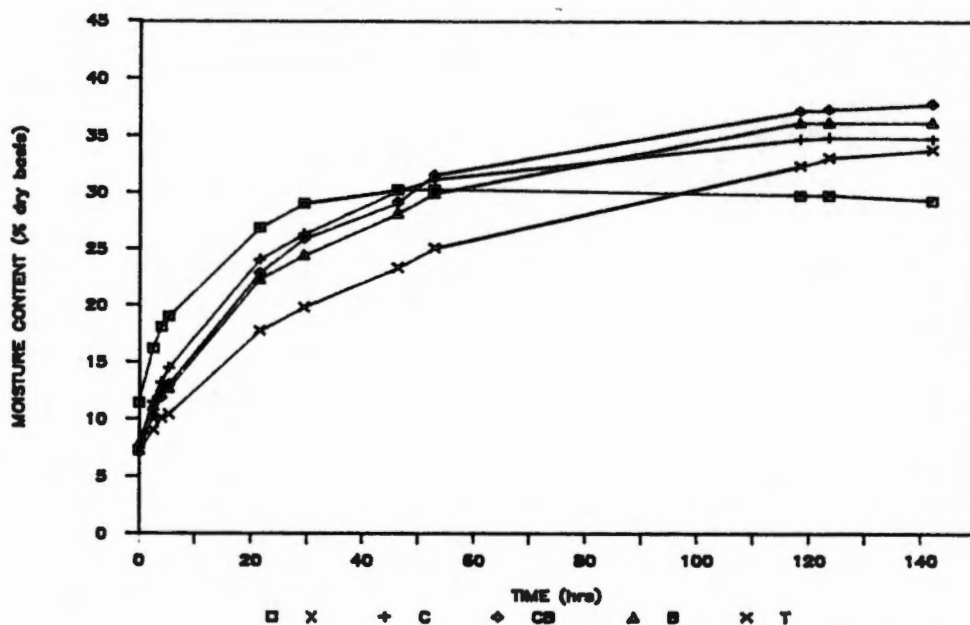


FIGURE A-11. Moisture Absorption Curves for the Second Replication at 0 °C, 85% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

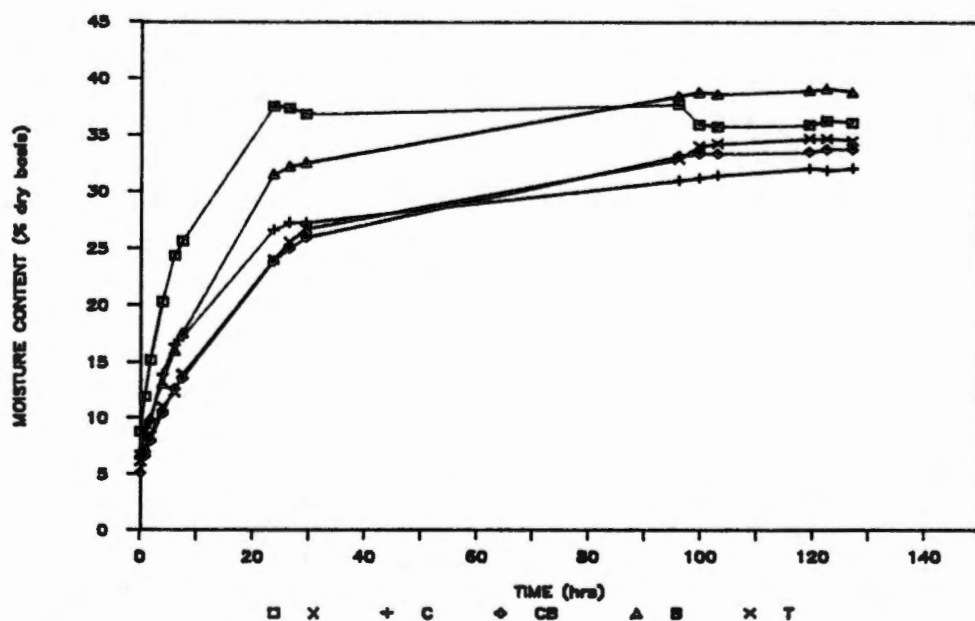


FIGURE A-12. Moisture Absorption Curves for the Third Replication at 0 °C, 86% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

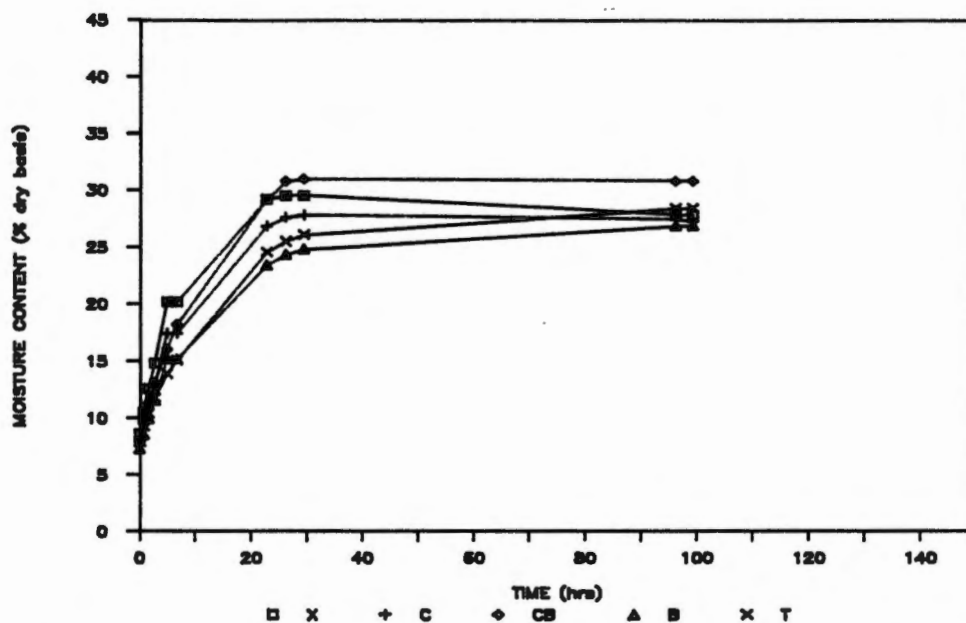


FIGURE A-13. Moisture Absorption Curves for the First Replication at 0 °C, 78% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

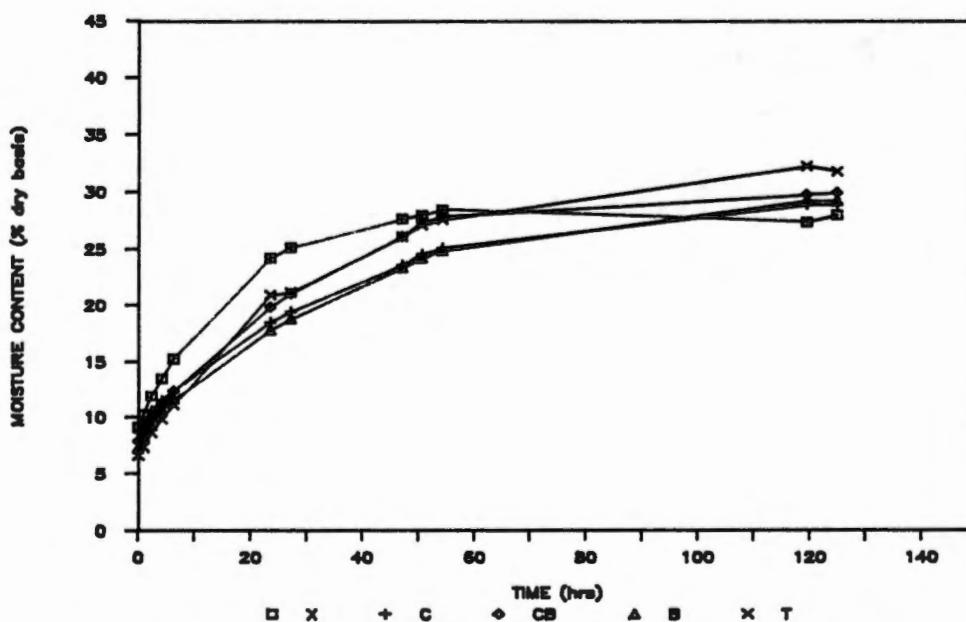


FIGURE A-14. Moisture Absorption Curves for the Second Replication at 0 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

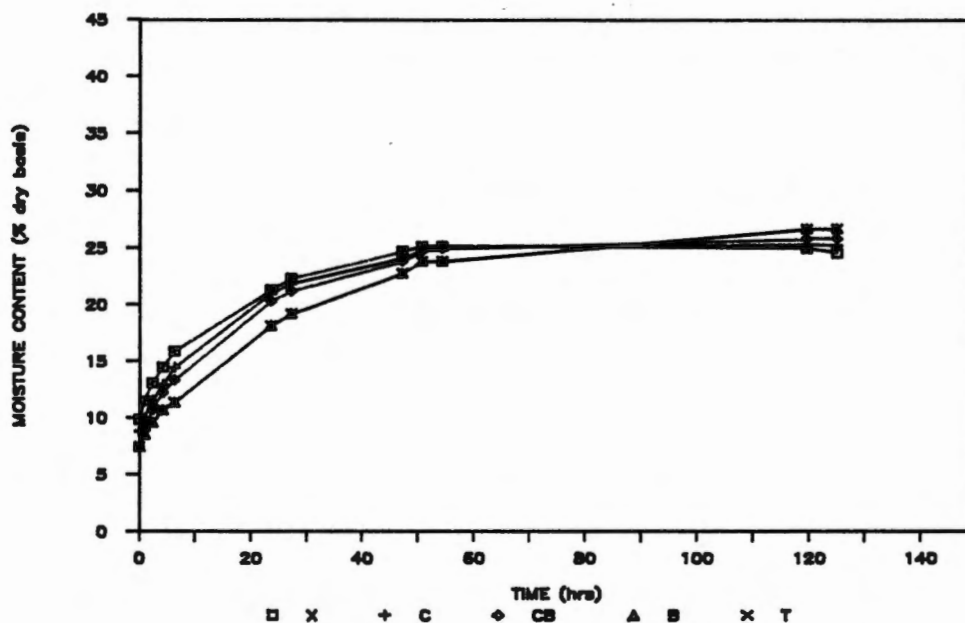


FIGURE A-15. Moisture Absorption Curves for the Third Replication at 0 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

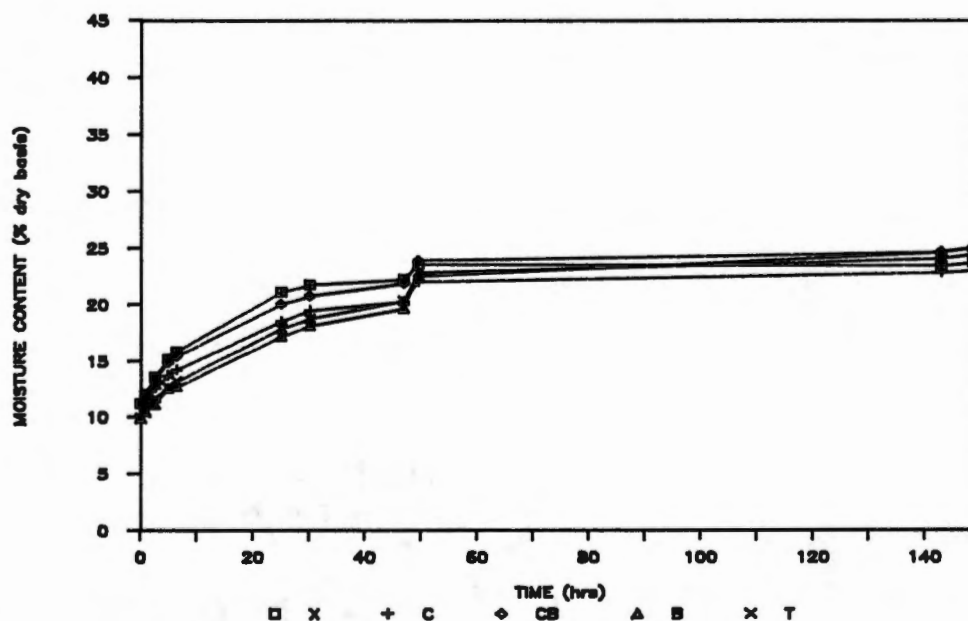


FIGURE A-16. Moisture Absorption Curves for the First Replication at 5 °C, 72% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

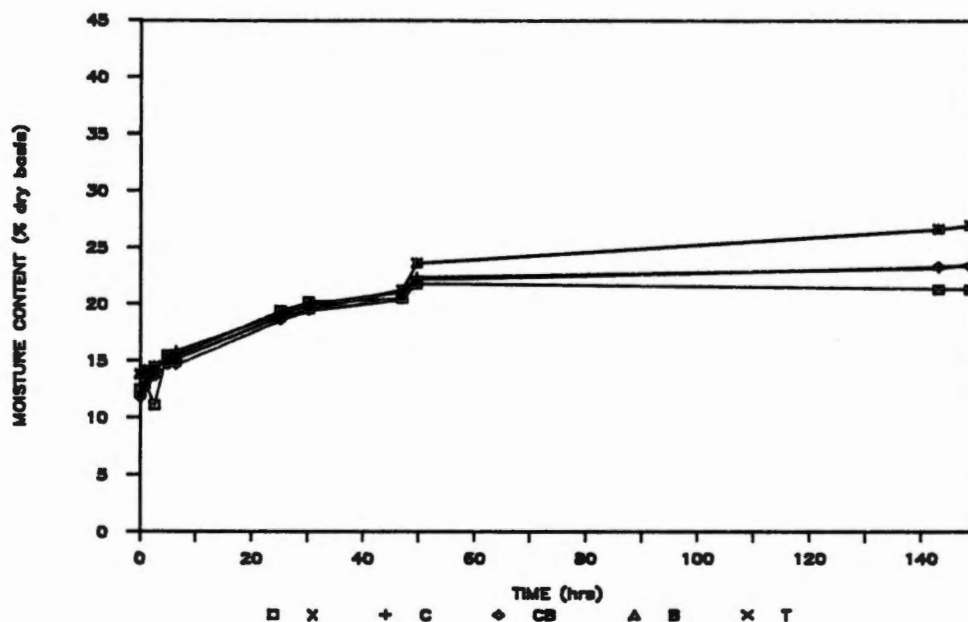


FIGURE A-17. Moisture Absorption Curves for the Second Replication at 5 °C, 72% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

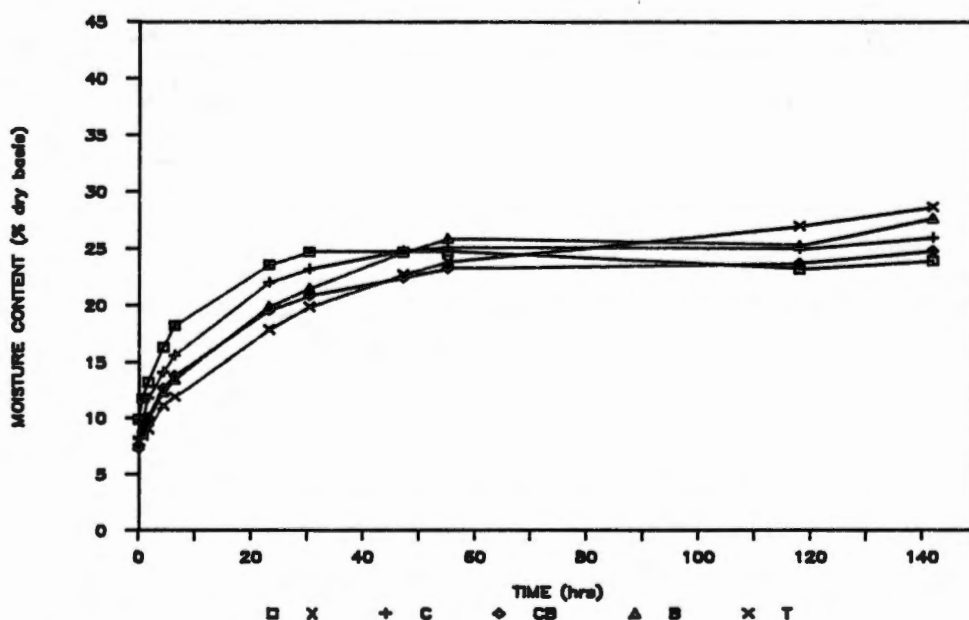


FIGURE A-18. Moisture Absorption Curves for the Third Replication at 5 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

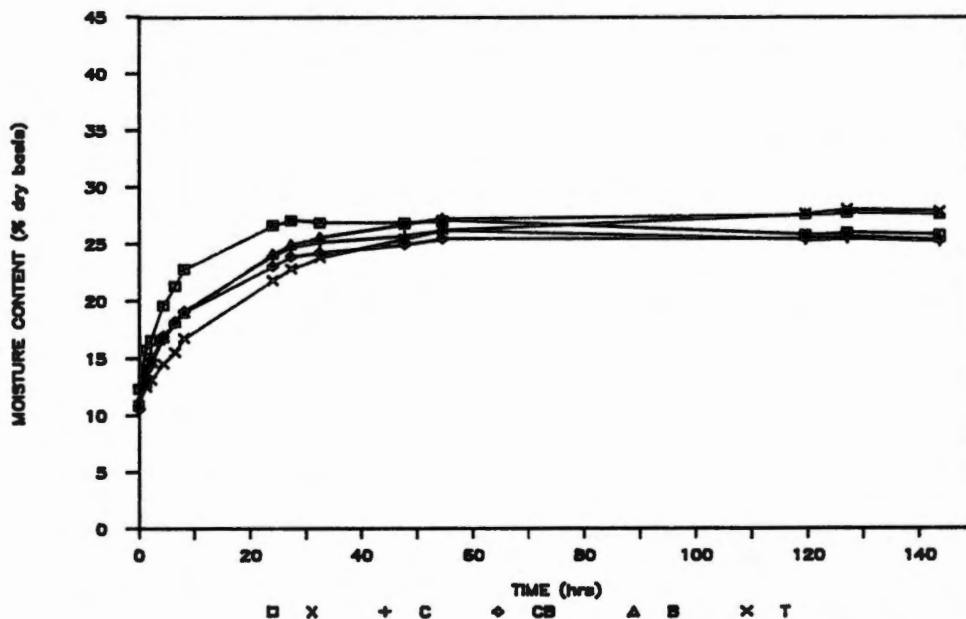


FIGURE A-19. Moisture Absorption Curves for the First Replication at 10 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

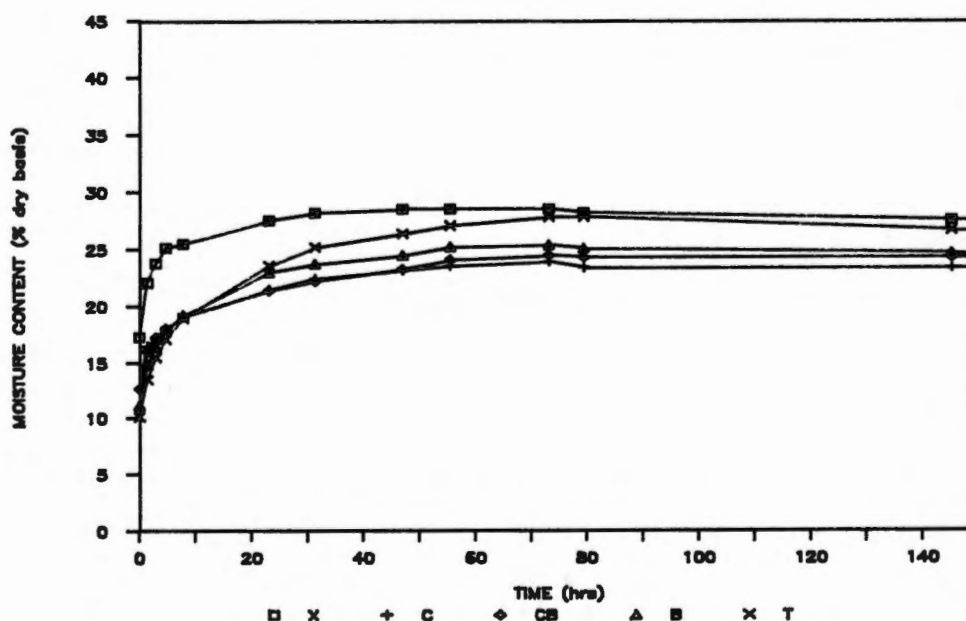


FIGURE A-20. Moisture Absorption Curves for the Second Replication at 10 °C, 74% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

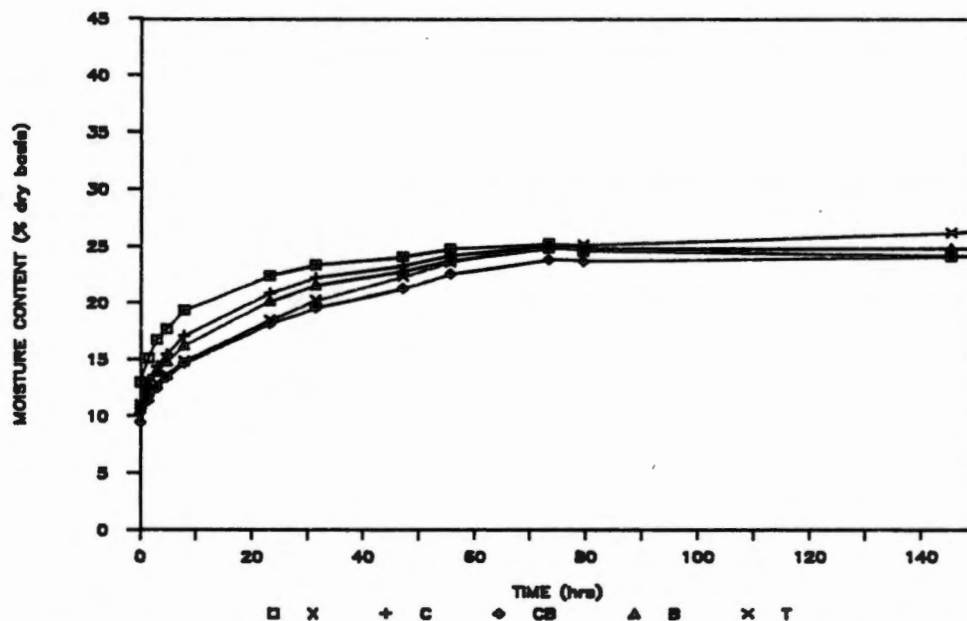


FIGURE A-21. Moisture Absorption Curves for the Third Replication at 10 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

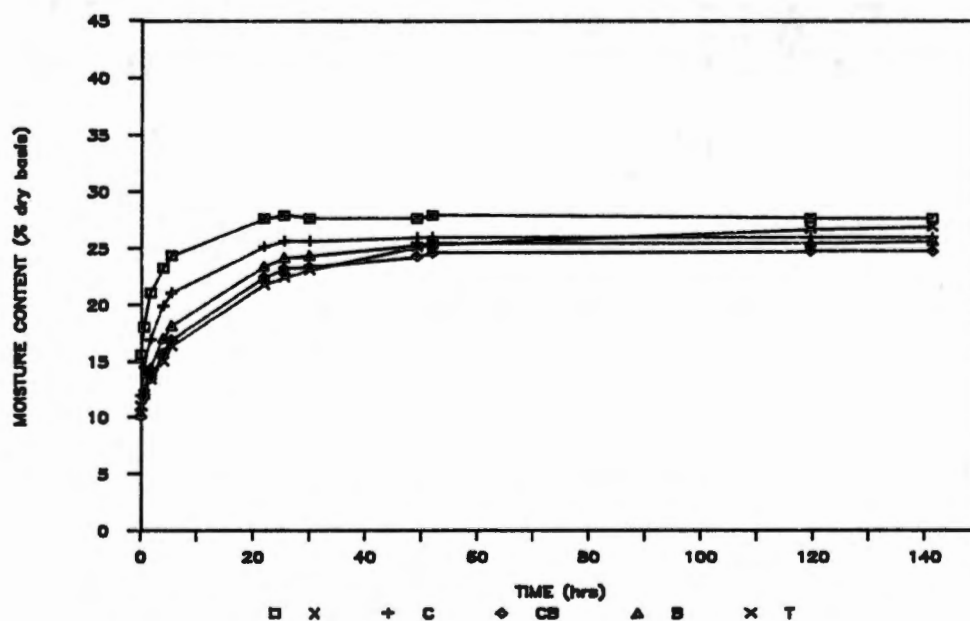


FIGURE A-22. Moisture Absorption Curves for the First Replication at 15 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

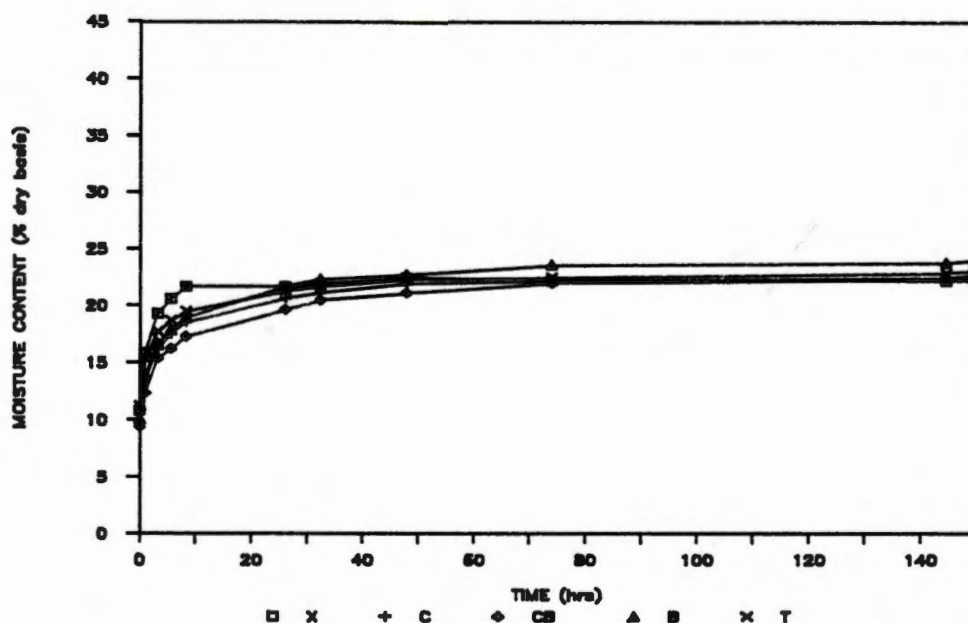


FIGURE A-23. Moisture Absorption Curves for the Second Replication at 15 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

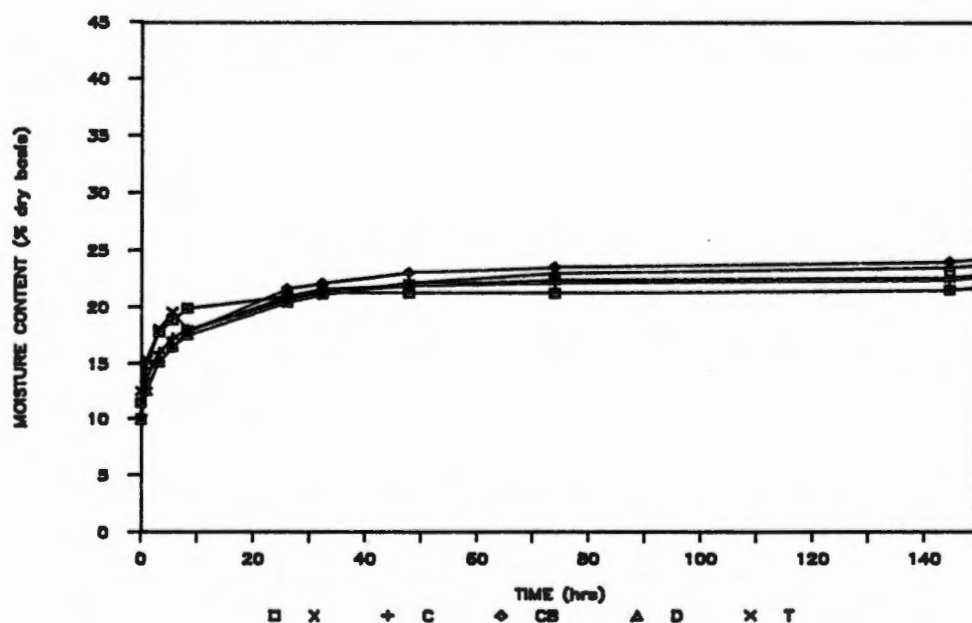


FIGURE A-24. Moisture Absorption Curves for the Third Replication at 15 °C, 75% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

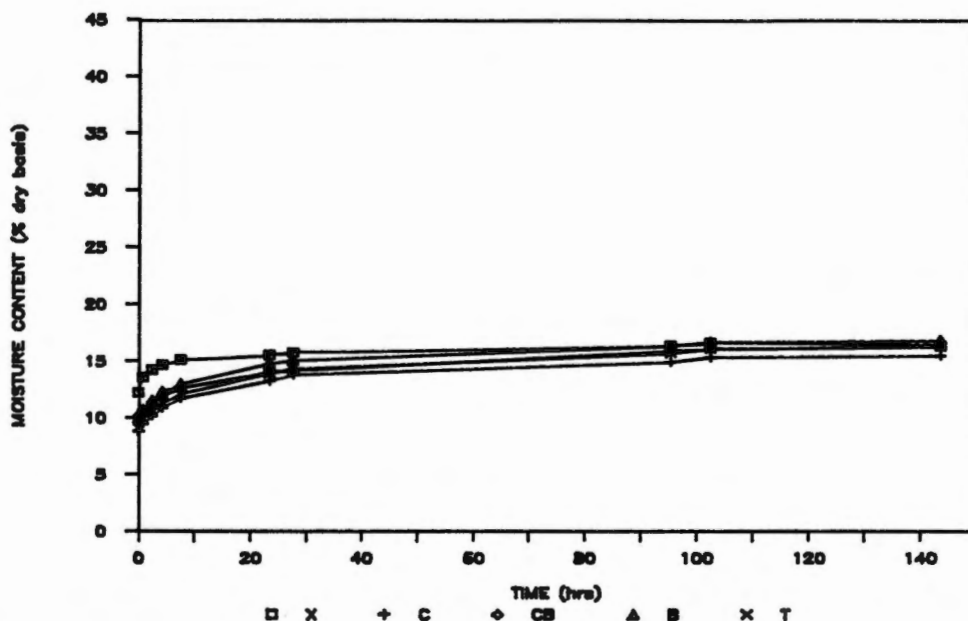


FIGURE A-25. Moisture Absorption Curves for the First Replication at 15 °C, 55% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

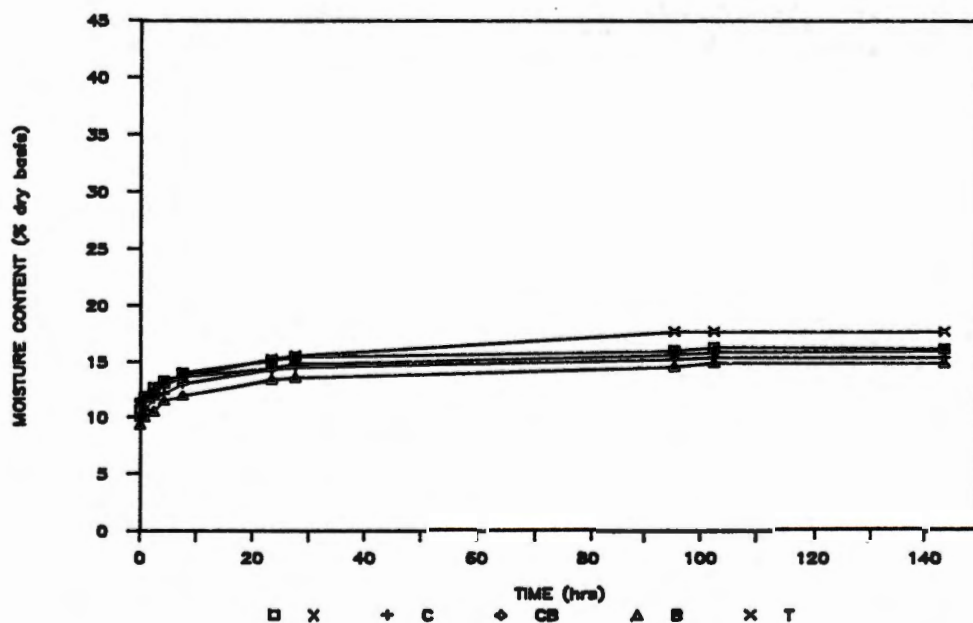


FIGURE A-26. Moisture Absorption Curves for the Second Replication at 15 °C, 55% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

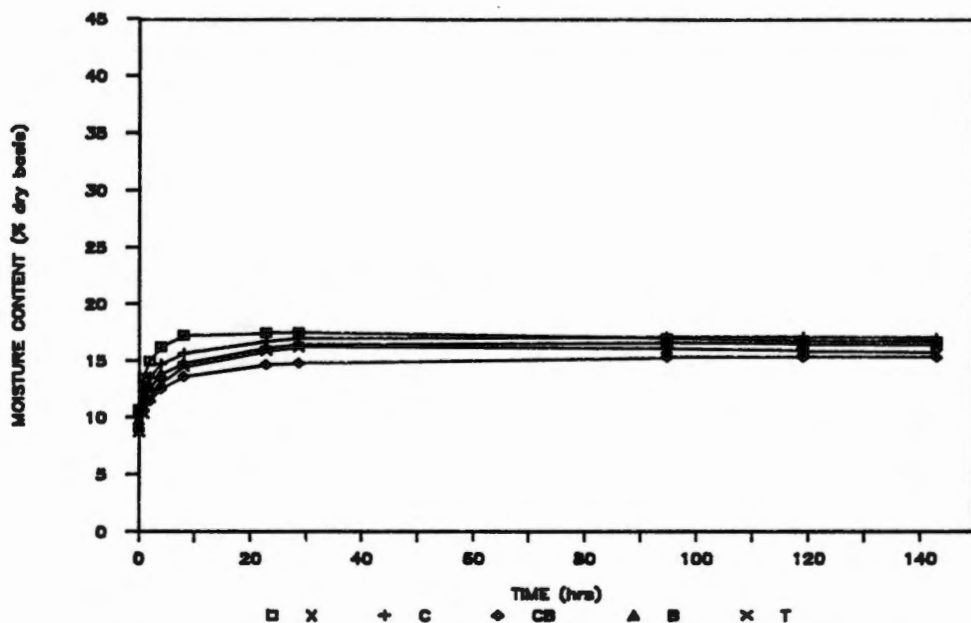


FIGURE A-27. Moisture Absorption Curves for the Third Replication at 15 °C, 59% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

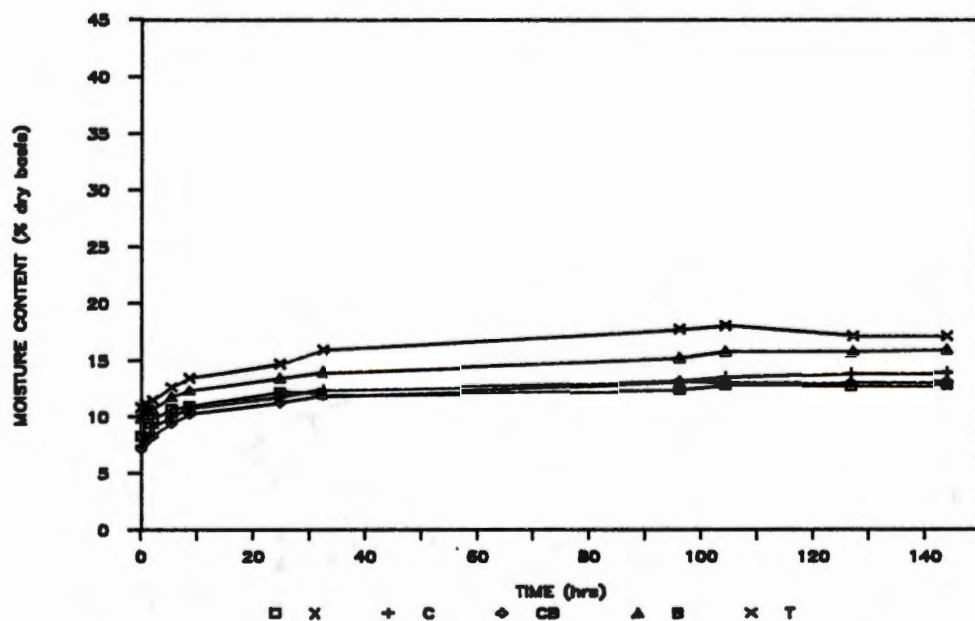


FIGURE A-28. Moisture Absorption Curves for the First Replication at 10 °C, 52% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

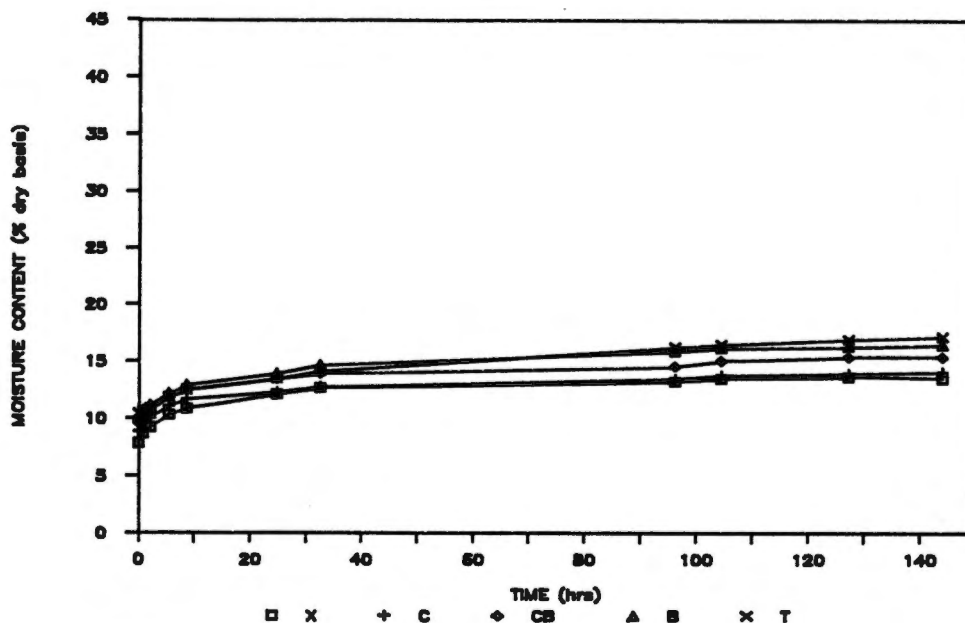


FIGURE A-29. Moisture Absorption Curves for the Second Replication at 10 °C, 52% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

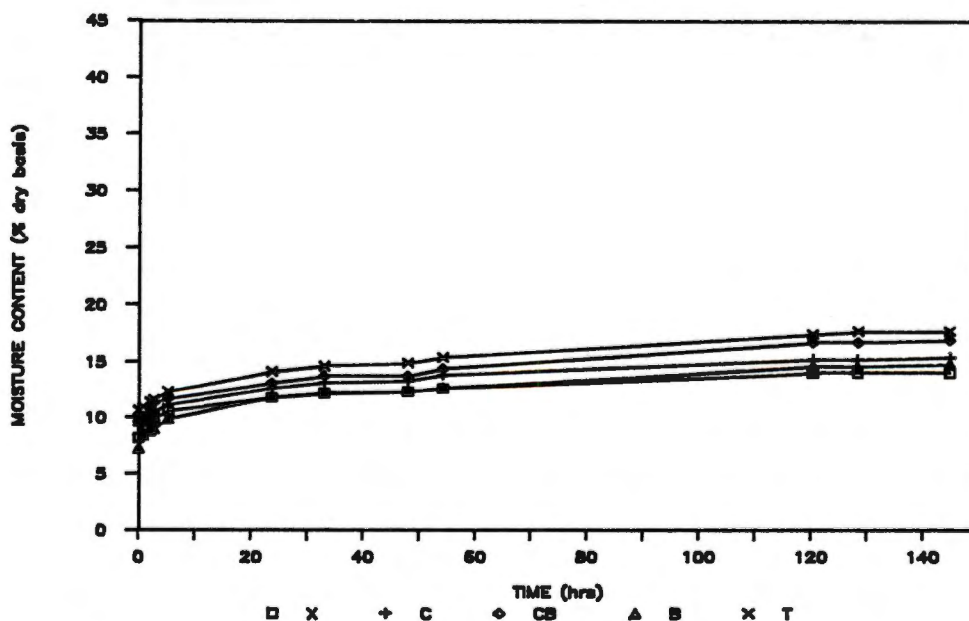


FIGURE A-30. Moisture Absorption Curves for the Third Replication at 10 °C, 52% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

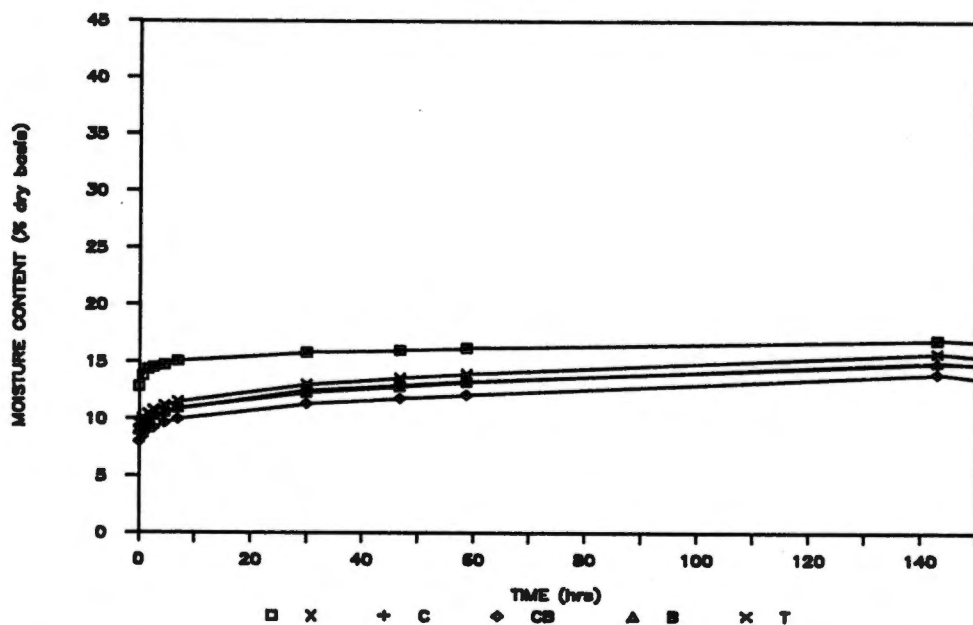


FIGURE A-31. Moisture Absorption Curves for the First Replication at 5 °C, 53% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

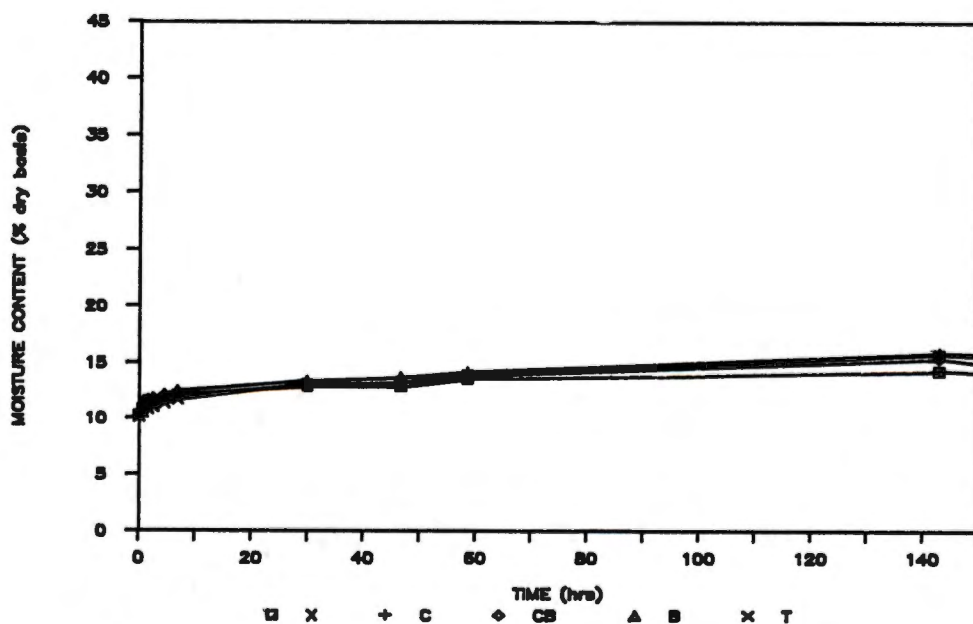


FIGURE A-32. Moisture Absorption Curves for the Second Replication at 5 °C, 52% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

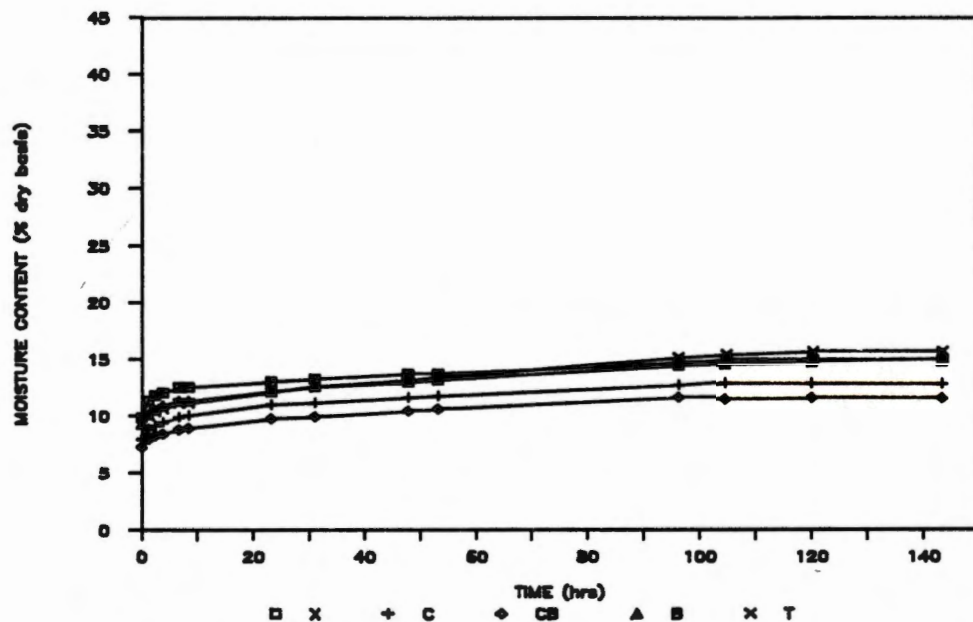


FIGURE A-33. Moisture Absorption Curves for the Third Replication at 5 °C, 50% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

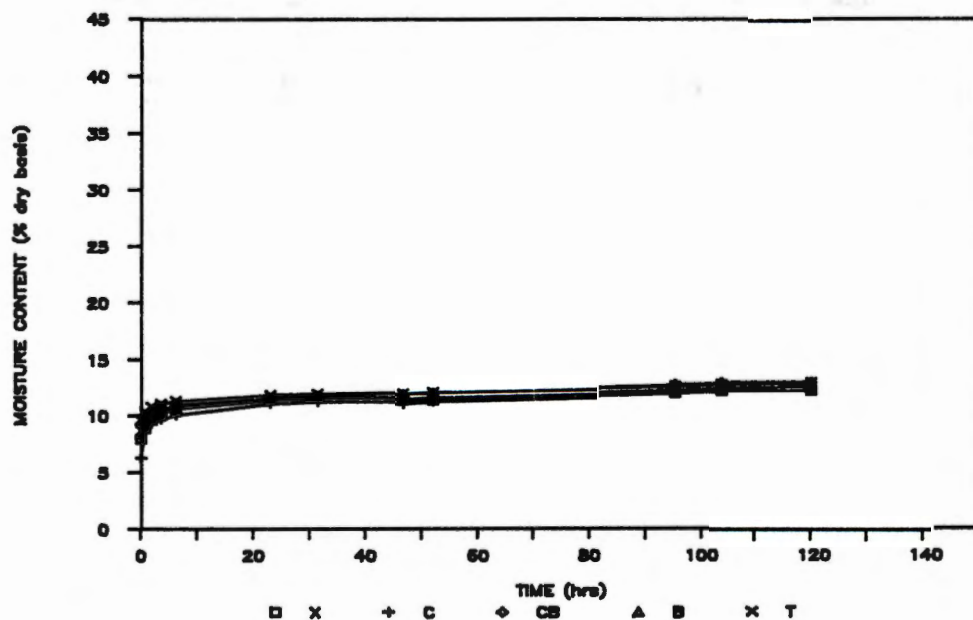


FIGURE A-34. Moisture Absorption Curves for the First Replication at 0 °C, 49% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

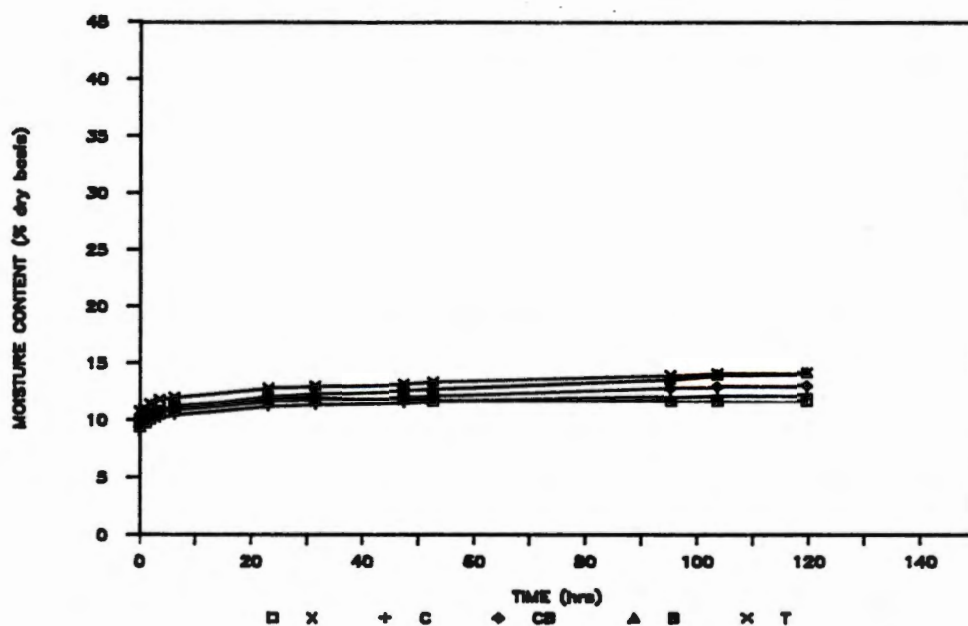


FIGURE A-35. Moisture Absorption Curves for the Second Replication at 0 °C, 49% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

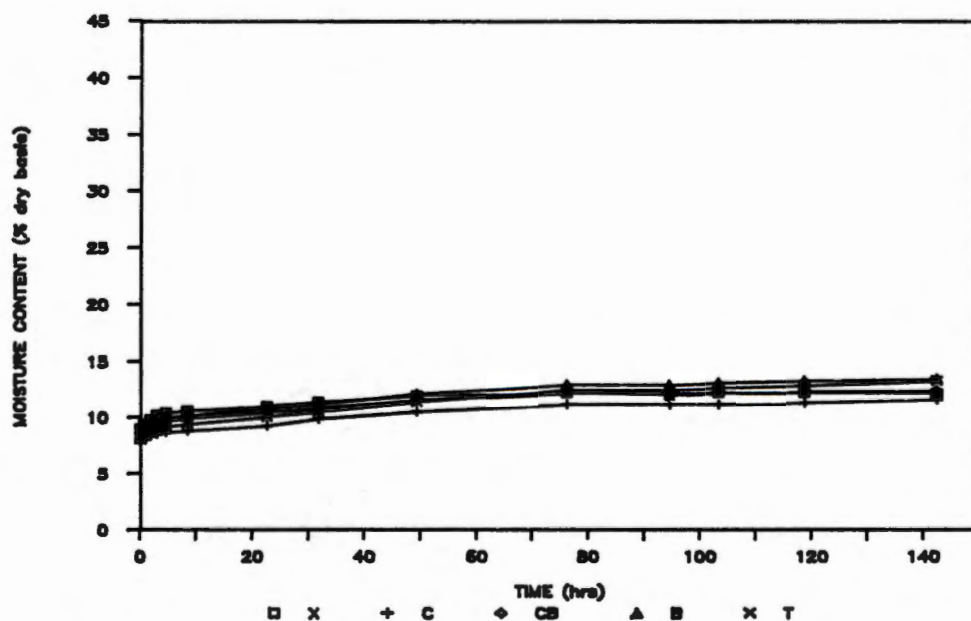


FIGURE A-36. Moisture Absorption Curves for the Third Replication at 0 °C, 47% RH. X, C, CB, B and T Signify Stalk Positions from Bottom to Top of the Stalk.

APPENDIX B.

Data for the Moisture Absorption Experiment

Table B-1. Moisture Content Values for the First Replication Tested at 15 °C, 89% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	12.28	10.98	11.23	10.74	9.63
0.33	14.06	12.67	12.71	12.32	11.05
1.20	16.55	14.53	14.62	14.22	12.66
2.65	18.68	16.22	16.10	16.11	13.90
3.80	20.82	17.74	18.01	17.85	15.33
20.30	31.85	28.21	29.45	28.44	27.09
20.47	32.21	28.72	29.87	29.54	27.81
20.63	32.56	29.22	30.30	29.86	28.70
20.80	33.10	30.07	31.14	30.81	29.77
116.67	35.41	35.81	36.86	36.65	38.32

Table B-2. Moisture Content Values for the Second Replication Tested at 15 °C, 89% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	13.96	10.50	11.75	8.58	10.35
0.75	17.01	12.67	13.33	10.53	11.99
1.85	20.56	15.64	16.19	13.06	13.90
3.05	22.84	17.23	18.10	14.62	15.53
4.30	24.37	19.01	19.68	16.37	17.44
7.00	26.40	21.58	22.54	18.71	20.16
22.25	29.70	29.31	29.84	27.68	30.79
24.90	29.70	29.90	30.79	28.46	31.88
29.60	29.70	30.89	32.22	30.02	33.51
50.40	29.95	33.27	35.40	33.33	37.87
54.30	29.70	33.27	35.56	33.33	38.15
71.60	29.70	33.86	36.51	34.50	39.24
74.55	29.70	33.86	36.67	34.70	39.51
76.85	29.44	33.86	36.83	34.70	39.51
143.00	28.93	33.66	36.51	34.89	39.78

Table B-3. Moisture Content Values for the Third Replication Tested at 15 °C, 88% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	10.20	9.38	8.86	9.42	9.64
0.80	13.03	12.40	11.88	11.66	11.72
2.50	16.33	15.08	14.69	14.57	14.06
3.70	18.52	16.75	16.63	16.37	15.89
6.30	21.19	19.10	19.22	19.06	18.23
23.70	28.41	28.64	27.86	28.70	27.86
27.00	28.89	29.48	28.51	29.60	29.17
30.00	29.20	29.98	29.37	30.49	29.69
47.40	30.61	33.17	31.53	33.18	33.07
50.60	30.77	33.17	31.97	33.41	33.85
53.30	30.61	33.33	31.97	33.41	34.11
71.30	31.24	34.51	32.61	34.53	35.68
76.40	31.40	34.84	33.05	34.98	36.20
95.07	31.08	34.51	33.05	34.98	36.46

Table B-4. Moisture Content Values for the First Replication Tested at 10 °C, 85% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	6.72	7.64	7.00	7.06	6.52
0.50	8.24	9.71	8.66	8.65	7.76
1.60	10.20	12.26	10.87	10.81	9.63
2.70	11.71	14.01	12.34	12.39	11.02
5.60	14.75	17.36	15.47	15.56	13.82
22.60	24.30	29.30	26.34	27.38	24.69
26.40	25.60	29.78	27.99	28.96	26.55
29.35	26.03	30.57	28.36	29.68	27.64
46.60	29.07	34.24	33.52	33.72	32.45
50.40	29.72	34.55	33.52	34.44	33.23
70.20	30.80	36.31	36.65	36.31	36.18
74.70	30.37	36.46	36.65	36.46	36.49
77.60	30.37	36.31	36.65	36.60	36.65
142.20	32.10	38.06	39.04	38.18	39.44
148.00	31.67	37.90	38.49	37.90	39.29

Table B-5. Moisture Content Values for the Second Replication Tested at 10 °C, 85% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	10.94	11.52	7.59	13.49	8.19
1.50	14.78	14.68	11.47	16.91	11.30
3.00	18.23	18.22	12.28	19.24	13.56
5.15	21.50	20.82	16.80	21.94	15.82
22.85	30.71	31.60	29.40	27.70	26.55
26.60	32.05	31.41	31.66	29.86	28.81
31.00	32.44	32.53	32.96	31.12	30.51
46.80	33.21	33.64	36.51	35.07	34.75
51.25	33.01	34.20	37.32	35.61	35.88
70.50	33.78	36.62	39.42	38.13	38.98
78.30	33.21	35.69	39.74	38.49	39.27
146.00	32.44	36.25	40.87	39.75	41.24
147.70	32.63	36.25	40.71	39.75	41.24

Table B-6. Moisture Content Values for the Third Replication Tested at 10 °C, 85% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	12.69	10.57	9.04	9.50	10.38
0.71	15.67	13.36	11.98	12.09	12.19
2.57	20.15	17.77	15.72	16.12	15.12
5.00	23.88	21.44	18.66	19.14	18.74
6.75	25.37	23.49	20.43	20.86	20.32
23.60	30.35	32.75	31.83	30.50	32.05
28.70	30.60	33.33	33.40	31.51	34.09
52.60	31.84	36.42	39.29	36.26	40.63
55.60	31.34	35.98	39.10	36.26	41.08
77.50	31.59	36.12	40.08	37.70	42.44
143.00	31.84	36.56	39.88	38.13	44.70
148.30	30.85	35.54	39.29	37.99	44.24

Table B-7. Moisture Content Values for the First Replication Tested at 5 °C, 87% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	13.93	10.85	11.09	10.97	11.11
0.80	15.67	12.98	12.61	11.70	11.81
2.67	18.57	16.17	14.96	13.71	13.43
4.05	20.50	17.87	16.30	14.63	14.35
5.50	21.86	19.36	17.14	15.54	15.05
23.20	32.30	29.79	25.21	24.50	25.00
26.60	32.69	29.36	26.22	25.78	26.39
47.00	33.85	31.28	29.92	29.62	32.18
51.30	33.66	32.98	30.25	30.71	33.10
53.30	33.46	32.98	30.25	31.08	33.33
118.60	34.82	35.11	34.62	38.57	37.96
123.75	35.01	35.53	34.79	39.12	38.66

Table B-8. Moisture Content Values for the Second Replication Tested at 5 °C, 86% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	12.78	9.25	10.26	8.66	10.20
0.75	15.01	11.53	12.18	10.23	10.70
1.80	16.02	12.66	13.46	11.65	11.44
4.70	19.27	15.75	16.35	14.63	13.18
6.70	20.89	17.05	18.27	15.91	14.18
23.40	30.22	25.97	25.48	24.29	22.39
27.80	30.83	27.11	26.92	25.57	24.13
30.70	30.83	27.60	27.24	26.14	25.12
47.30	32.86	30.84	30.13	30.97	29.85
54.25	32.25	31.01	29.81	31.25	30.60
143.65	34.89	37.18	33.49	35.23	36.82
147.75	34.08	36.69	33.01	35.51	36.82

Table B-9. Moisture Content Values for the Third Replication Tested at 5 °C, 86% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	10.06	7.53	8.56	8.61	5.70
0.70	11.45	8.97	9.91	10.44	6.58
3.90	16.48	12.16	12.91	13.92	9.21
6.50	19.27	14.04	14.56	15.75	10.53
23.75	29.61	21.85	22.37	23.63	20.18
26.50	29.89	22.58	22.97	24.54	21.05
30.35	30.73	23.59	24.02	25.64	22.81
47.85	34.36	26.92	28.23	27.84	28.51
50.00	34.64	27.64	28.68	28.21	28.95
54.15	34.92	28.36	29.58	28.94	29.39
71.85	34.64	29.23	30.78	30.40	31.14
77.75	34.92	29.38	30.78	30.95	31.58
143.80	34.92	30.82	31.83	33.33	33.33
145.80	34.64	30.82	31.83	33.52	33.33

Table B-10. Moisture Content Values for the First Replication Tested at 0 °C, 85% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	9.50	8.69	8.12	7.26	7.39
2.55	13.82	13.93	12.90	11.82	10.86
4.00	15.72	15.86	14.81	13.53	13.12
5.30	17.44	17.38	16.08	14.81	14.48
21.50	27.63	28.97	28.03	24.93	27.30
29.40	29.19	31.59	30.89	27.49	30.17
46.30	31.26	34.48	35.51	31.05	32.43
52.90	32.12	35.17	37.90	32.76	34.69
118.30	33.68	35.86	43.79	37.46	39.67
123.50	33.51	36.83	44.59	37.32	39.37
142.00	32.99	35.86	46.50	38.75	39.67

Table B-11. Moisture Content Values for the Second Replication Tested at 0 °C, 86% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	11.43	7.41	7.09	7.83	7.32
2.55	16.19	11.54	10.31	11.15	9.06
4.00	18.10	13.25	11.92	12.72	10.10
5.30	19.05	14.53	13.04	12.72	10.45
21.50	26.90	24.07	22.87	22.31	17.77
29.40	29.05	26.35	25.93	24.46	19.86
46.30	30.24	30.20	29.15	28.18	23.34
52.90	30.24	31.20	31.56	29.94	25.09
118.30	29.76	34.76	37.20	36.20	32.40
123.50	29.76	34.90	37.36	36.20	33.10
142.00	29.29	34.76	37.84	36.20	33.80

Table B-12. Moisture Content Values for the Third Replication Tested at 0 °C, 80% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	8.79	6.99	5.11	6.75	6.16
0.87	11.90	9.17	6.63	8.43	7.31
1.85	15.20	9.83	7.95	9.95	8.45
4.00	20.33	13.97	10.42	13.15	10.96
6.15	24.36	16.59	12.69	16.02	12.33
7.52	25.64	17.25	13.64	17.54	13.93
23.70	37.55	26.64	23.86	31.53	23.97
26.50	37.36	27.29	25.00	32.21	25.57
29.50	36.81	27.29	25.95	32.55	26.71
96.20	37.73	31.00	33.14	38.45	32.88
99.80	35.90	31.22	33.33	38.79	34.02
103.10	35.71	31.44	33.33	38.62	34.25
119.50	35.90	32.10	33.52	38.95	34.70
122.60	36.26	31.88	33.71	39.12	34.70
127.20	36.08	32.10	33.71	38.79	34.47

Table B-13. Moisture Content Values for the First Replication Tested at 0 °C, 78% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	8.64	8.06	7.87	7.28	7.93
0.78	10.54	9.79	9.51	8.54	9.28
1.65	12.61	11.32	11.31	9.97	10.44
2.74	14.85	12.86	13.11	11.55	11.80
4.94	20.21	17.47	16.07	15.19	13.93
6.67	20.21	17.47	18.20	15.19	15.09
22.71	29.19	26.87	29.18	23.42	24.56
26.13	29.53	27.64	30.82	24.37	25.53
29.35	29.53	27.83	30.98	24.84	26.11
96.22	27.81	27.45	30.82	26.90	28.43
99.27	27.81	27.26	30.82	26.90	28.43

Table B-14. Moisture Content Values for the Second Replication Tested at 0 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	9.12	8.70	7.84	7.23	6.65
1.00	10.22	9.64	8.89	8.24	7.39
2.37	11.95	10.59	9.93	9.24	8.62
4.25	13.52	11.53	11.15	10.59	9.85
6.30	15.25	12.48	12.37	11.60	11.08
23.57	24.21	18.53	19.86	17.82	20.94
27.20	25.16	19.47	21.08	18.82	21.18
47.20	27.67	23.63	26.13	23.36	26.11
50.72	27.99	24.57	27.35	24.20	27.09
54.37	28.46	25.14	27.87	24.87	27.59
119.58	27.36	28.92	29.79	29.24	32.27
125.05	27.99	28.92	29.97	29.24	31.77

Table B-15. Moisture Content Values for the Third Replication Tested at 0 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	9.86	8.79	7.44	7.87	7.47
1.00	11.47	10.00	8.97	8.57	8.54
2.37	13.08	11.55	10.72	9.62	9.61
4.25	14.49	12.93	12.25	10.66	10.68
6.30	15.90	14.48	13.35	11.54	11.39
23.57	21.33	21.03	20.35	17.83	18.15
27.20	22.33	21.90	21.23	18.71	19.22
47.20	24.75	24.14	23.85	22.38	22.78
50.72	25.15	24.83	24.73	23.25	23.84
54.37	25.15	25.17	24.95	23.60	23.84
119.58	24.95	25.34	25.82	26.75	26.69
125.05	24.55	25.17	25.82	26.75	26.69

Table B-16. Moisture Content Values for the First Replication Tested at 5 °C, 72% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	11.22	10.79	11.05	9.94	9.93
0.87	12.18	11.27	11.79	10.52	10.46
2.58	13.62	12.70	13.44	11.09	11.70
4.90	15.22	13.81	14.92	12.62	12.77
6.42	15.87	14.29	15.47	12.81	13.30
25.07	21.15	18.57	20.07	17.21	17.91
30.15	21.79	19.52	20.81	18.16	18.79
47.05	22.28	20.32	21.92	19.69	20.38
49.62	23.56	22.06	23.94	22.56	22.87
143.03	23.40	22.86	24.68	24.67	24.11
148.73	23.72	23.02	25.05	25.05	24.47

Table B-17. Moisture Content Values for the Second Replication Tested at 5 °C, 72% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	11.13	11.97	11.77	11.51	13.85
0.87	12.54	12.95	12.63	12.23	14.19
2.58	13.17	14.26	13.65	13.38	14.53
4.90	15.52	15.25	14.68	14.53	15.20
6.42	15.52	15.90	14.68	14.82	15.20
25.07	19.44	19.18	18.60	18.99	18.92
30.15	20.22	20.00	19.45	19.42	19.59
47.05	20.53	21.15	20.48	20.72	21.28
49.62	21.79	22.46	22.18	22.45	23.65
143.03	21.32	23.28	23.38	22.88	26.69
148.73	21.32	23.61	23.38	23.02	27.03

Table B-18. Moisture Content Values for the Third Replication Tested at 5 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	9.89	8.14	7.32	7.57	7.95
0.77	11.79	9.76	8.76	8.76	8.52
1.73	13.31	11.83	10.03	9.76	9.09
4.40	16.35	14.20	12.74	12.35	11.08
6.40	18.25	15.68	13.85	13.55	11.93
23.22	23.57	22.04	19.59	19.92	17.90
30.42	24.71	23.22	20.86	21.51	19.89
47.23	24.71	24.85	22.45	24.70	22.73
55.20	24.71	25.15	23.25	25.90	23.86
118.08	23.19	25.00	23.73	25.30	26.99
141.97	23.95	26.04	24.84	27.69	28.69

Table B-19. Moisture Content Values for the First Replication Tested at 10 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	12.37	10.60	10.57	11.24	10.91
1.35	15.78	13.55	14.04	12.89	12.53
2.22	16.63	14.43	14.90	14.71	13.13
4.42	19.62	16.64	16.98	16.86	14.55
6.47	21.32	18.11	18.20	18.18	15.56
8.08	22.81	19.15	19.06	19.01	16.77
23.97	26.65	24.01	23.05	24.13	21.82
27.27	27.08	24.74	23.92	24.96	22.83
32.42	26.87	25.18	24.26	25.62	23.84
47.72	26.87	25.77	24.96	26.78	25.45
54.50	27.08	26.22	25.48	27.27	26.26
119.55	25.80	25.33	25.48	27.60	27.68
127.02	26.01	25.48	25.65	27.77	28.08
143.65	25.80	25.18	25.30	27.60	27.88

Table B-20. Moisture Content Values for the Second Replication Tested at 10 °C, 74% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	17.35	12.67	12.68	11.13	10.18
1.43	22.11	16.51	16.01	14.89	13.57
2.97	23.81	17.27	17.26	16.39	15.49
4.70	25.17	18.04	18.09	17.89	17.11
7.83	25.51	19.19	19.13	19.25	19.03
23.08	27.55	21.50	21.41	23.01	23.60
31.32	28.23	22.46	22.25	23.76	25.22
47.08	28.57	23.22	23.28	24.51	26.40
55.58	28.57	23.61	24.12	25.26	27.14
73.30	28.57	23.99	24.53	25.41	27.88
79.52	28.23	23.42	24.32	25.11	27.88
145.30	27.55	23.42	24.32	24.66	26.70
166.83	27.55	23.22	24.12	24.36	26.55

Table B-21. Moisture Content Values for the Third Replication Tested at 10 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	13.00	10.99	9.48	10.64	11.05
1.43	15.13	13.25	11.37	12.83	12.08
2.97	16.78	14.46	12.48	13.93	12.85
4.70	17.73	15.51	13.43	14.87	13.62
7.83	19.39	17.17	14.69	16.28	14.91
23.08	22.46	20.93	18.18	20.19	18.51
31.32	23.40	22.29	19.59	21.60	20.31
47.08	24.11	23.34	21.33	22.85	22.37
55.58	24.82	24.25	22.59	23.79	23.65
73.30	25.30	25.15	23.85	24.88	25.19
79.52	24.59	24.85	23.70	24.73	25.19
145.30	24.11	24.85	24.17	24.88	26.22
166.83	24.11	24.55	24.17	24.73	26.99

Table B-22. Moisture Content Values for the First Replication Tested at 15 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	15.62	11.95	10.09	10.32	11.01
0.58	18.08	14.57	11.77	12.38	12.13
1.75	21.10	17.02	13.61	14.45	13.48
4.00	23.29	19.97	15.75	17.07	15.06
5.47	24.38	21.11	16.97	18.20	16.40
21.88	27.67	25.20	22.48	23.45	21.80
25.48	27.95	25.70	23.24	24.20	22.47
29.98	27.67	25.70	23.39	24.39	23.15
49.28	27.67	26.02	24.31	25.33	25.17
52.05	27.95	26.02	24.62	25.52	25.39
119.62	27.67	26.02	24.77	25.52	26.74
141.42	27.67	26.02	24.77	25.70	26.97

Table B-23. Moisture Content Values for the Second Replication Tested at 15 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	10.85	9.69	9.40	10.13	11.27
1.05	15.87	13.61	12.39	13.92	15.29
3.25	19.31	16.23	15.38	16.67	17.71
5.63	20.63	17.54	16.24	17.93	18.71
8.30	21.69	18.59	17.31	18.99	19.52
26.07	21.69	20.68	19.66	21.73	21.33
32.37	21.96	21.20	20.51	22.36	21.73
47.92	22.49	21.99	21.15	22.78	22.33
74.03	22.22	22.25	22.01	23.63	22.54
144.53	22.22	22.51	22.44	23.84	22.94
149.75	22.22	22.77	22.65	24.05	23.14

Table B-24. Moisture Content Values for the Third Replication Tested at 15 °C, 75% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	11.44	10.34	10.00	9.98	12.55
1.05	14.89	13.70	12.86	12.56	15.32
3.25	17.82	16.02	15.24	15.15	18.09
5.63	18.88	17.31	16.43	16.52	19.57
8.30	19.95	18.09	17.86	17.56	17.98
26.07	21.01	20.67	21.67	20.48	20.96
32.37	21.28	21.45	22.14	21.17	21.60
47.92	21.28	21.96	23.10	22.20	22.02
74.03	21.28	22.22	23.57	23.06	22.45
144.53	21.54	22.48	24.05	23.58	22.66
149.75	21.81	22.74	24.29	23.75	22.87

Table B-25. Moisture Content Values for the First Replication Tested at 15 °C, 55% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	12.28	8.84	10.12	9.93	9.18
0.83	13.60	9.54	10.63	10.75	9.98
2.45	14.25	10.24	11.32	11.56	10.58
4.28	14.69	10.94	12.01	12.38	11.38
7.58	15.13	11.78	12.69	13.03	12.18
23.37	15.57	13.32	14.07	14.82	13.97
27.65	15.79	13.88	14.24	15.15	14.37
95.38	16.45	15.01	15.95	16.45	15.77
102.48	16.67	15.43	16.12	16.78	16.17
143.57	16.45	15.57	16.47	16.94	16.37

Table B-26. Moisture Content Values for the Second Replication Tested at 15 °C, 55% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	10.65	9.73	11.43	9.39	11.31
0.83	11.93	10.63	11.61	10.05	11.93
2.45	12.78	11.71	12.32	10.54	12.23
4.28	13.35	12.25	13.04	11.53	13.15
7.58	14.06	13.15	13.75	12.03	13.76
23.37	15.20	14.41	14.46	13.51	15.29
27.65	15.48	14.59	14.82	13.67	15.60
95.38	16.05	15.32	15.71	14.66	17.74
102.48	16.34	15.50	15.89	14.99	17.74
143.57	16.19	15.50	16.07	14.99	17.74

Table B-27. Moisture Content Values for the Third Replication Tested at 15 °C, 59% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	10.66	10.60	8.83	9.76	8.75
0.87	13.45	12.35	10.60	11.62	10.36
1.95	14.97	13.56	11.48	12.63	11.79
4.02	16.24	14.77	12.54	13.80	13.04
8.07	17.26	15.70	13.60	14.81	14.46
22.75	17.51	16.78	14.66	16.16	15.89
28.63	17.51	17.05	14.84	16.50	16.25
94.70	17.01	17.18	15.37	16.67	16.07
118.93	16.75	17.18	15.37	16.50	15.89
142.85	16.75	17.05	15.37	16.50	15.71

Table B-28. Moisture Content Values for the First Replication Tested at 10 °C, 52% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	8.30	7.40	7.18	9.93	10.84
0.80	9.39	8.35	7.83	10.50	11.14
2.07	9.83	9.11	8.32	10.65	11.45
5.47	10.70	10.06	9.46	11.80	12.65
8.62	10.92	10.82	10.28	12.37	13.55
24.73	12.23	11.76	11.26	13.53	14.76
32.50	12.01	12.52	11.91	14.10	15.96
96.17	12.45	13.28	13.21	15.25	17.77
104.42	12.88	13.66	13.05	15.83	18.07
127.20	12.88	14.04	13.21	15.83	17.17
143.97	12.88	14.04	13.21	15.97	17.17

Table B-29. Moisture Content Values for the Second Replication Tested at 10 °C, 52% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	7.87	8.89	9.58	10.16	10.47
0.80	8.70	9.64	10.23	10.75	10.70
2.07	9.25	10.09	10.71	11.19	10.93
5.47	10.36	11.14	11.85	12.22	11.86
8.62	10.91	11.75	12.50	12.96	12.56
24.73	12.15	12.35	13.47	13.99	13.49
32.50	12.71	12.80	13.96	14.73	14.19
96.17	13.26	13.55	14.61	15.91	16.28
104.42	13.54	13.86	15.10	16.20	16.51
127.20	13.67	14.04	15.42	16.35	16.98
143.97	13.54	14.16	15.42	16.49	17.21

Table B-30. Moisture Content Values for the Third Replication Tested at 10 °C, 52% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	8.18	9.28	9.62	7.24	10.63
0.80	9.17	9.79	10.04	8.38	10.89
2.10	9.59	10.31	10.88	8.76	11.39
2.73	9.87	10.48	11.30	8.95	11.65
5.25	10.58	11.17	11.72	9.90	12.41
23.72	11.85	12.71	13.18	11.81	14.18
33.15	12.27	13.23	13.81	12.19	14.68
48.07	12.41	13.40	13.81	12.38	14.94
54.32	12.69	13.92	14.44	12.76	15.44
120.38	14.10	15.29	16.74	14.67	17.47
128.52	14.10	15.29	16.74	14.67	17.72
144.83	14.10	15.46	16.95	14.86	17.72

Table B-31. Moisture Content Values for the First Replication Tested at 5 °C, 53% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	12.85	8.68	8.00	9.09	9.70
0.67	13.80	9.49	8.46	9.50	10.07
1.67	14.37	9.97	9.08	10.18	10.45
2.58	14.56	10.29	9.23	10.31	10.82
4.60	14.74	10.45	9.69	10.58	11.19
6.95	15.12	10.93	10.00	10.99	11.57
29.97	15.88	12.54	11.38	12.35	13.06
46.75	16.07	13.02	11.85	12.89	13.62
58.67	16.26	13.34	12.15	13.30	13.99
143.00	17.01	14.95	14.00	15.06	15.86
150.48	16.82	14.79	13.54	14.79	15.49

Table B-32. Moisture Content Values for the Second Replication Tested at 5 °C, 52% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	X	C	CB	B	T
0.00	10.26	10.39	10.34	10.57	10.10
0.67	10.82	11.01	10.97	11.29	10.44
1.67	11.57	11.32	11.39	11.65	10.77
2.58	11.57	11.63	11.39	11.83	10.94
4.60	11.75	11.94	11.81	12.19	11.28
6.95	12.13	12.40	12.03	12.54	11.62
29.97	12.87	13.49	13.08	13.44	13.13
46.75	12.87	13.80	13.29	13.80	13.30
58.67	13.62	14.26	13.92	14.16	13.97
143.00	14.37	15.97	15.40	15.77	15.82
150.48	14.18	15.81	14.98	15.59	15.82

Table B-33. Moisture Content Values for the Third Replication Tested at 5 °C, 50% RH.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	9.90	7.93	7.26	9.30	9.37
1.20	11.35	8.86	7.94	10.12	10.13
2.45	11.84	9.18	8.28	10.54	10.38
3.80	12.08	9.49	8.45	10.95	10.63
6.65	12.56	9.95	8.78	11.36	11.14
8.42	12.56	10.11	8.95	11.36	11.14
23.08	13.04	11.04	9.80	12.19	12.15
30.95	13.29	11.20	9.97	12.60	12.66
47.75	13.77	11.66	10.47	13.02	13.16
53.05	13.77	11.82	10.64	13.22	13.42
96.20	14.73	12.75	11.66	14.46	15.19
104.78	14.98	13.06	11.66	14.67	15.44
120.25	14.98	13.06	11.82	14.88	15.70
143.40	14.98	13.06	11.82	15.08	15.70

Table B-34. Moisture Content Values for the First Replication Tested at 0 °C, 49% RH¹.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	8.01	6.30	9.13	8.45	9.70
0.83	9.09	8.59	9.90	9.12	10.38
1.92	9.86	9.35	10.28	9.63	10.79
3.57	10.32	9.73	10.54	10.30	11.07
6.25	10.63	10.11	10.93	10.64	11.34
23.03	11.40	11.07	11.57	11.49	11.89
31.47	11.56	11.26	11.83	11.66	12.02
47.35	11.56	11.26	12.08	11.66	12.16
52.65	11.56	11.45	12.21	11.82	12.30
95.38	12.02	12.02	12.85	12.33	12.70
103.67	12.17	12.21	12.98	12.50	12.84
119.67	12.17	12.21	12.98	12.67	12.98

¹The desired value of 55% relative humidity could not be attained, causing lower than expected moisture contents.

Table B-35. Moisture Content Values for the Second Replication Tested at 0 °C, 49% RH¹.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	<u>Stalk Positions</u>				
	<u>X</u>	<u>C</u>	<u>CB</u>	<u>B</u>	<u>T</u>
0.00	9.81	9.04	9.37	9.77	10.82
0.83	10.02	9.48	9.83	10.20	11.02
1.92	10.65	9.78	10.29	10.49	11.42
3.57	10.86	10.22	10.75	10.78	11.82
6.25	11.27	10.52	10.91	11.06	12.02
23.03	11.90	11.26	11.67	12.07	12.83
31.47	11.90	11.41	11.83	12.36	13.03
47.35	11.90	11.56	11.98	12.64	13.23
52.65	11.69	11.70	12.14	12.79	13.43
95.38	11.69	12.15	12.90	13.65	14.03
103.67	11.69	12.30	13.06	14.08	14.23
119.67	11.69	12.30	13.06	14.22	14.23

¹The desired value of 55% relative humidity could not be attained, causing lower than expected moisture contents.

Table B-36. Moisture Content Values for the Third Replication Tested at 0 °C, 47% RH¹.

Conditioning Time (h)	Moisture Contents (% dry basis)				
	Stalk Positions				
	X	C	CB	B	T
0.00	9.02	7.90	8.60	8.47	8.13
0.70	9.42	8.09	8.98	8.98	8.57
1.78	9.82	8.40	9.48	9.49	8.79
2.98	10.22	8.55	9.60	9.66	9.01
4.58	10.42	8.71	9.73	10.00	9.23
8.40	10.62	8.86	9.98	10.17	9.45
22.58	11.02	9.33	10.47	10.85	10.11
31.78	11.42	9.95	10.85	11.19	10.55
49.43	12.02	10.58	11.60	12.20	11.43
76.20	12.22	11.20	12.22	13.05	12.53
94.70	12.02	11.20	12.22	13.05	12.53
103.40	12.22	11.20	12.22	13.22	12.75
118.70	12.22	11.35	12.34	13.39	12.97
142.40	12.22	11.66	12.47	13.56	13.41

¹The desired value of 55% relative humidity could not be attained, causing lower than expected moisture contents.

APPENDIX C.

Figures for the Preliminary Drying Tests

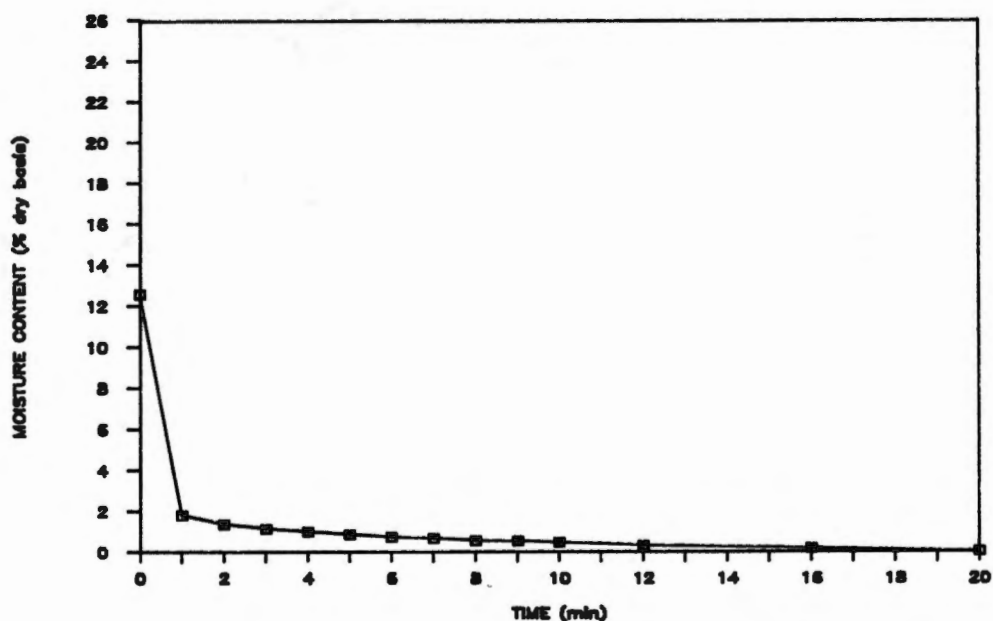


FIGURE C-1. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 1-mm Particle Size and Initially Conditioned at 58% RH.

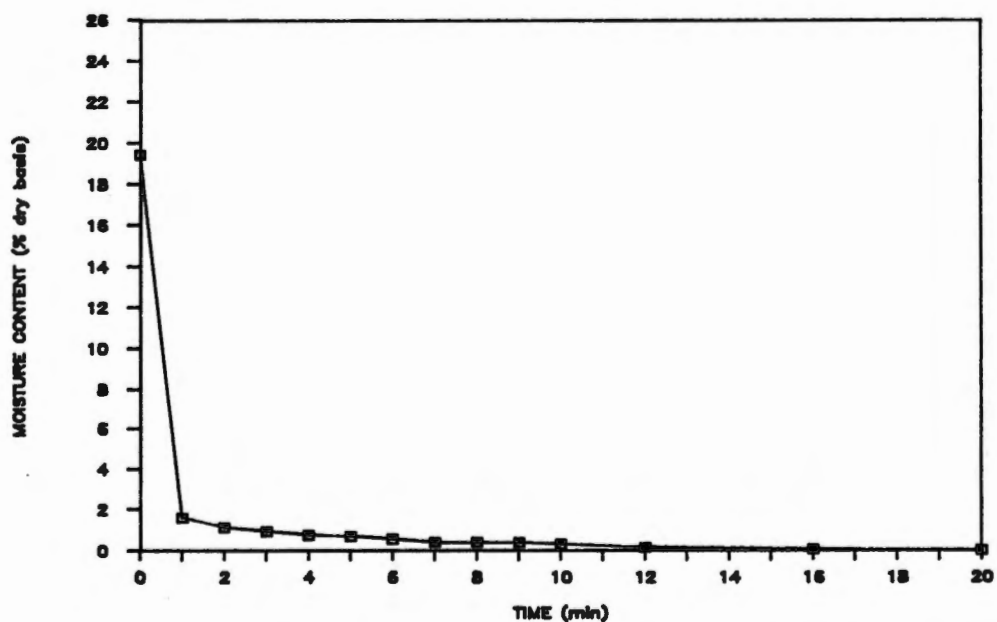


FIGURE C-2. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 1-mm Particle Size and Initially Conditioned at 76% RH.

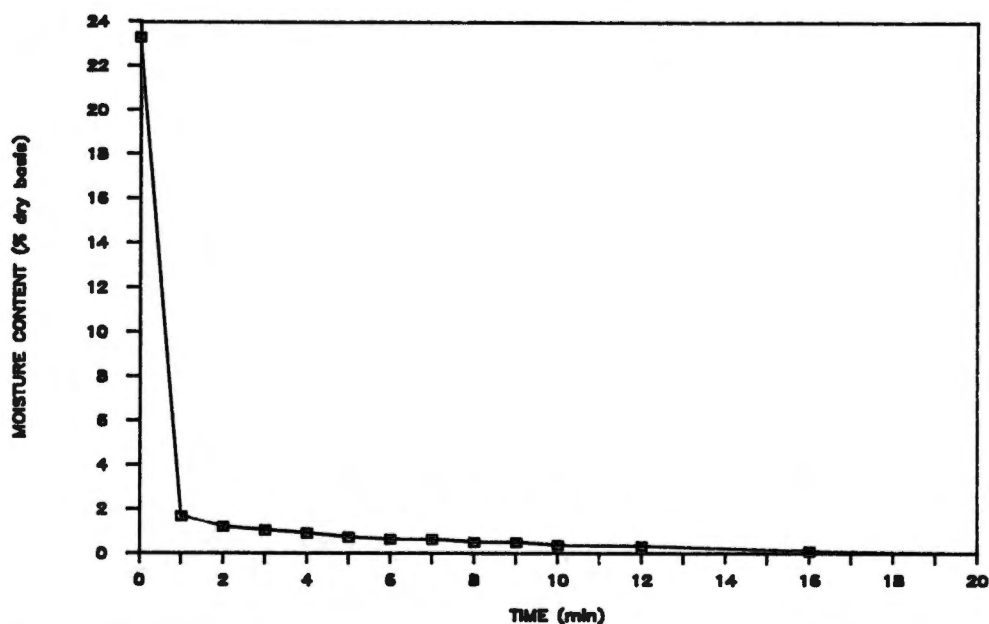


FIGURE C-3. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 1-mm Particle Size and Initially Conditioned at 88% RH.

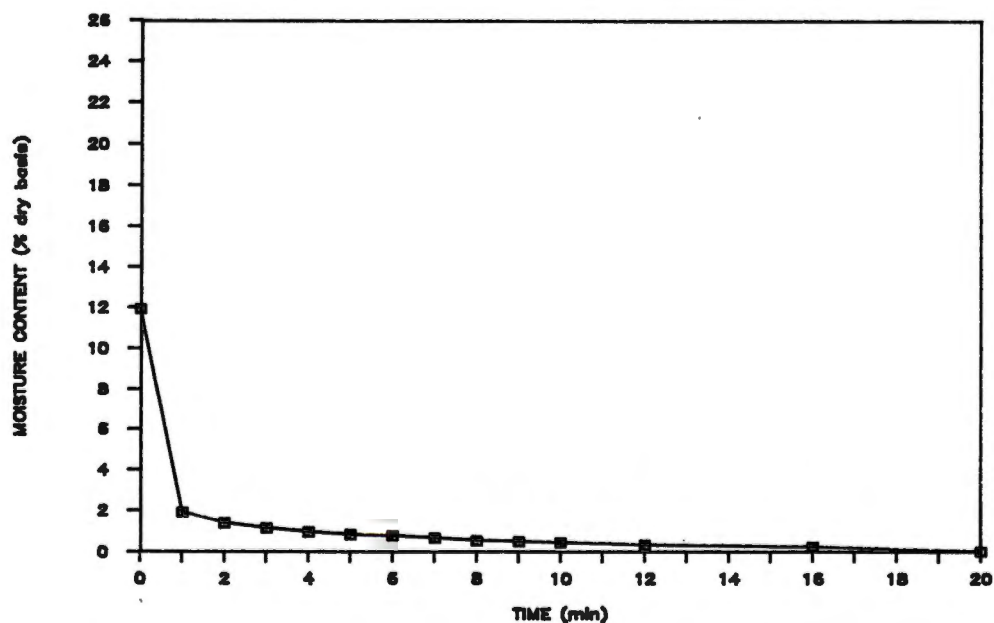


FIGURE C-4. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 3-mm Particle Size and Initially Conditioned at 58% RH.

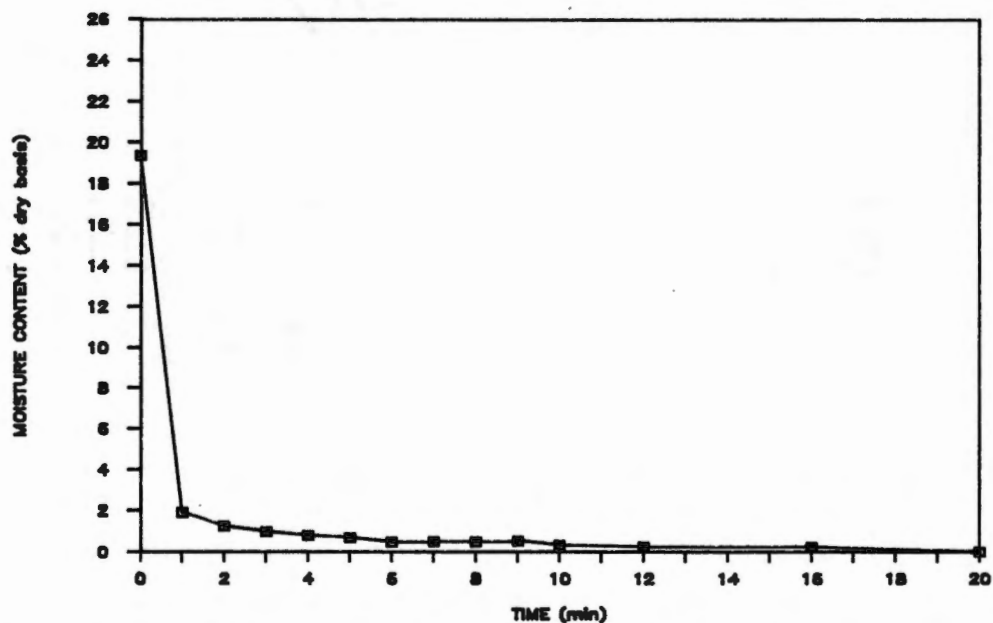


FIGURE C-5. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 3-mm Particle Size and Initially Conditioned at 76% RH.

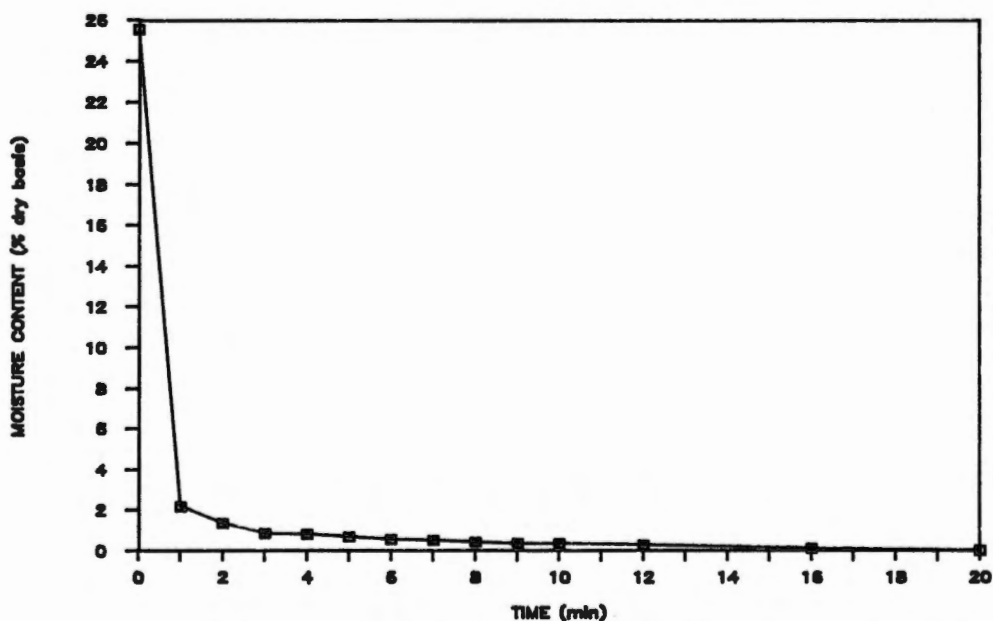


FIGURE C-6. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 3-mm Particle Size and Initially Conditioned at 88% RH.

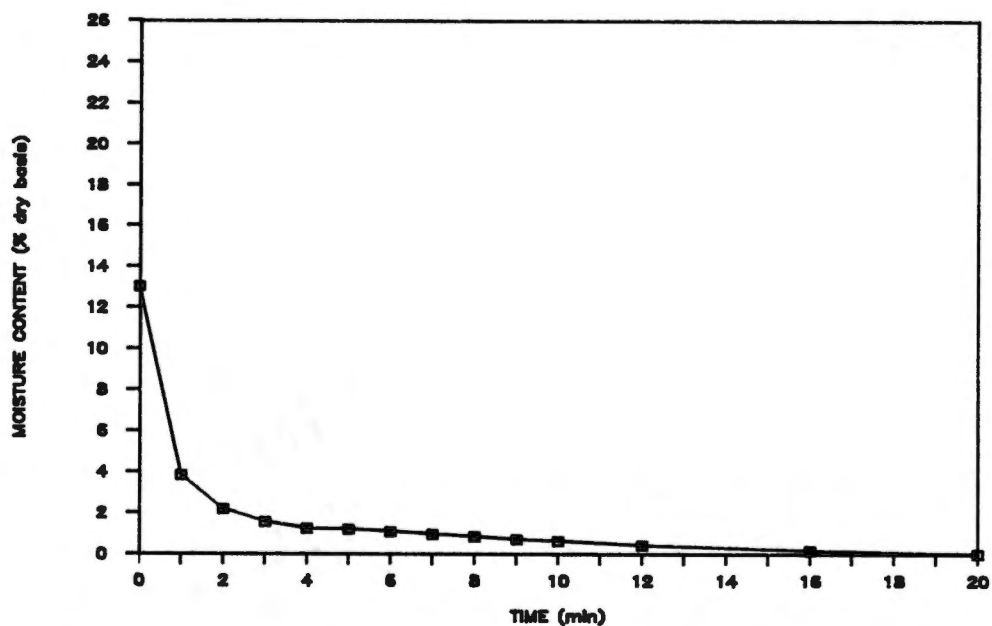


FIGURE C-7. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 6-mm Shred Size and Initially Conditioned at 58% RH.

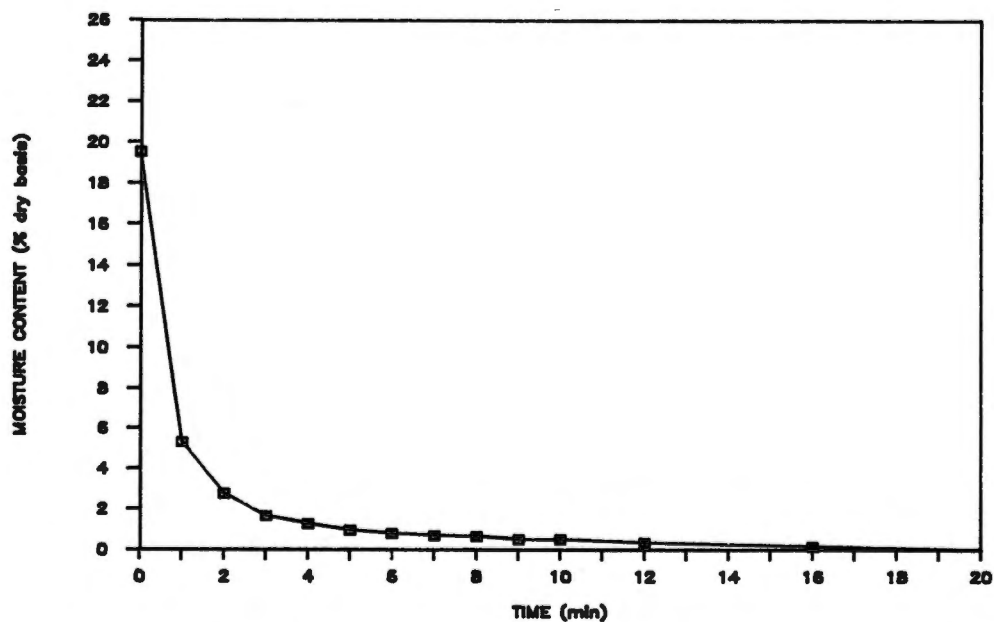


FIGURE C-8. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 6-mm Shred Size and Initially Conditioned at 76% RH.

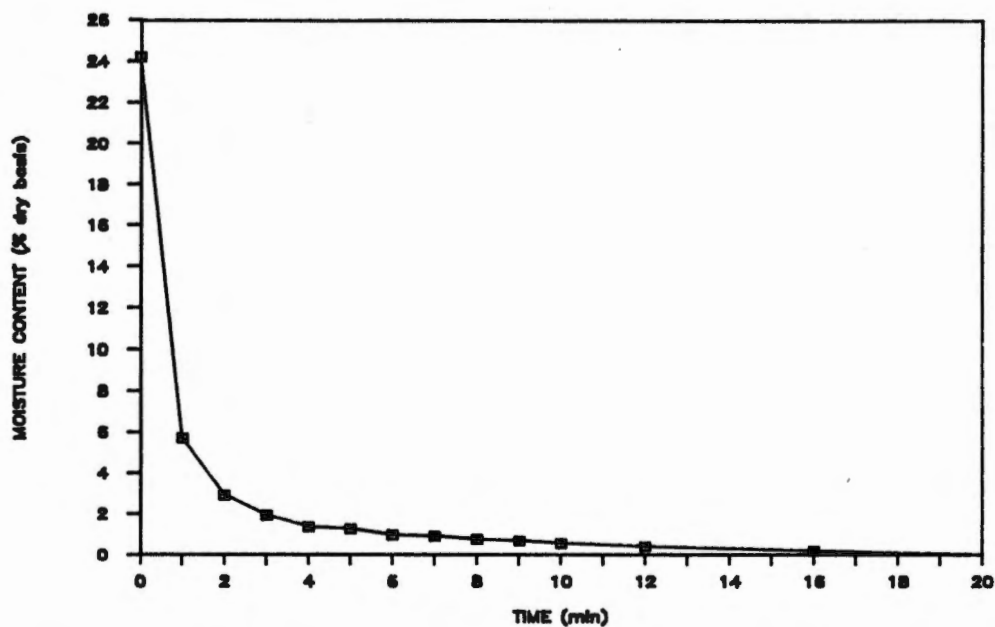


FIGURE C-9. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 6-mm Shred Size and Initially Conditioned at 88% RH.

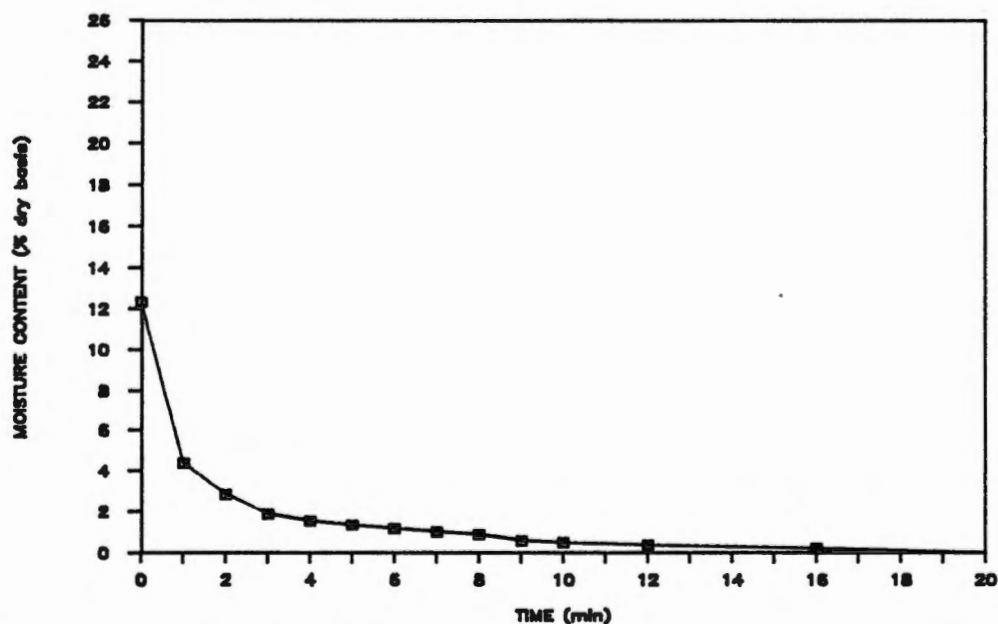


FIGURE C-10. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 25-mm Shred Size and Initially Conditioned at 58% RH.

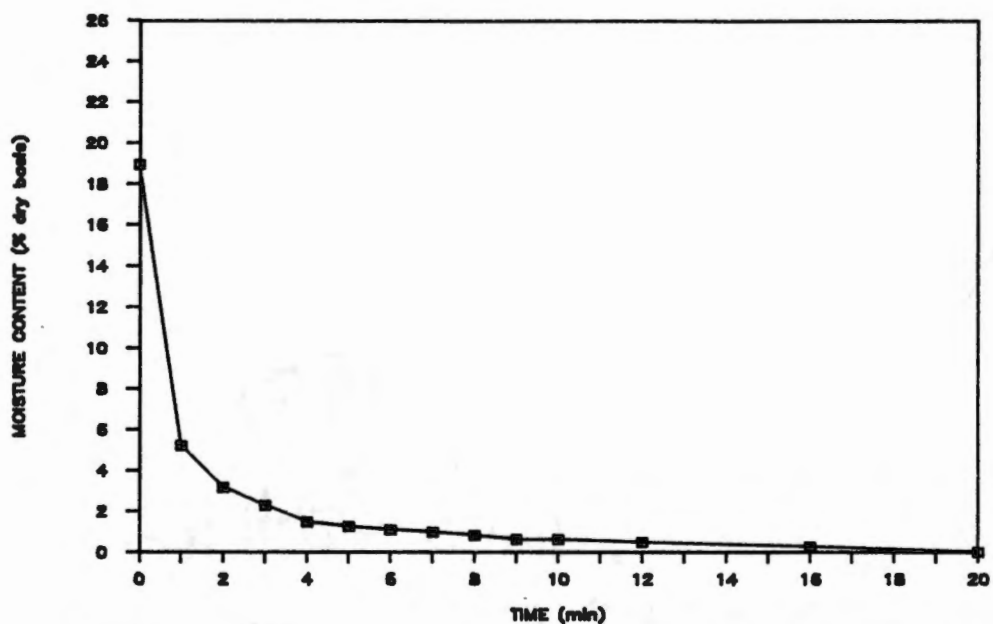


FIGURE C-11. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 25-mm Shred Size and Initially Conditioned at 76% RH.

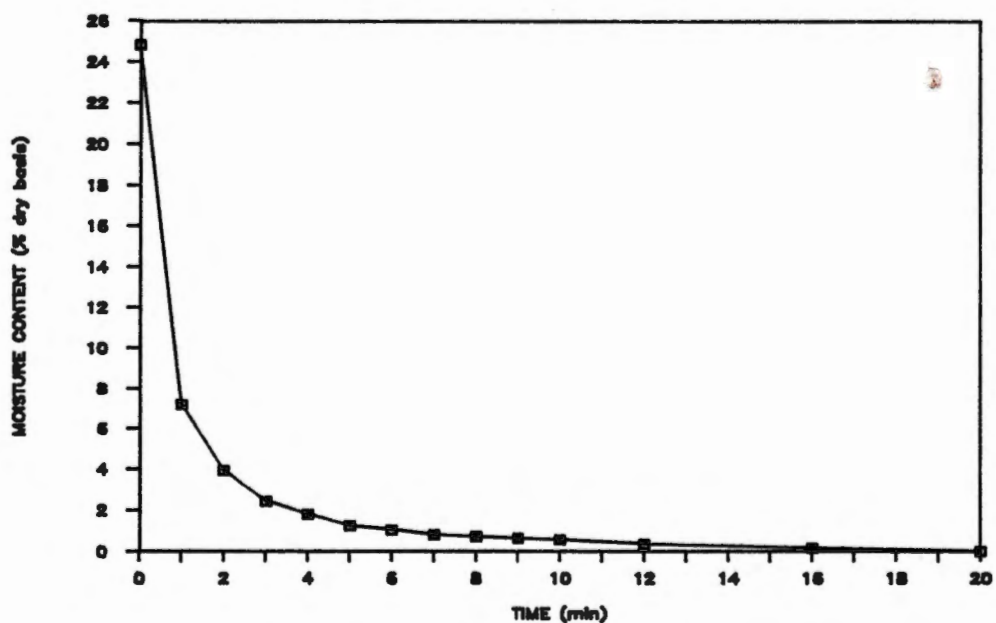


FIGURE C-12. Rate of Moisture Loss in the Hot-Air-Blast Oven for Top Stalk Burley Tobacco Ground to Nominal 25-mm Shred Size and Initially Conditioned at 88% RH.

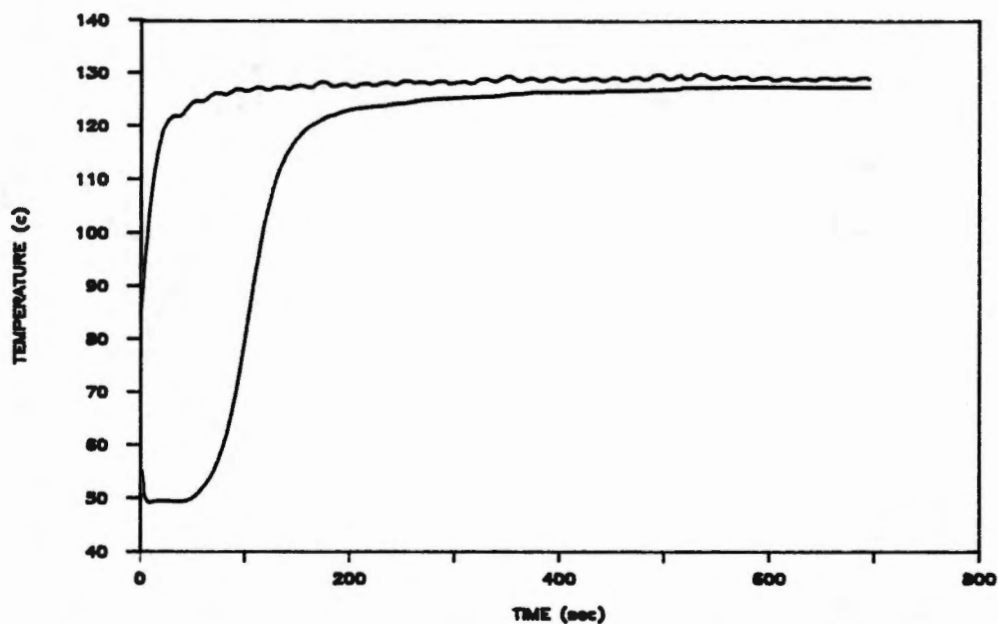


FIGURE C-13. Temperature History Curves for a 1-mm Particle Size, 58% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

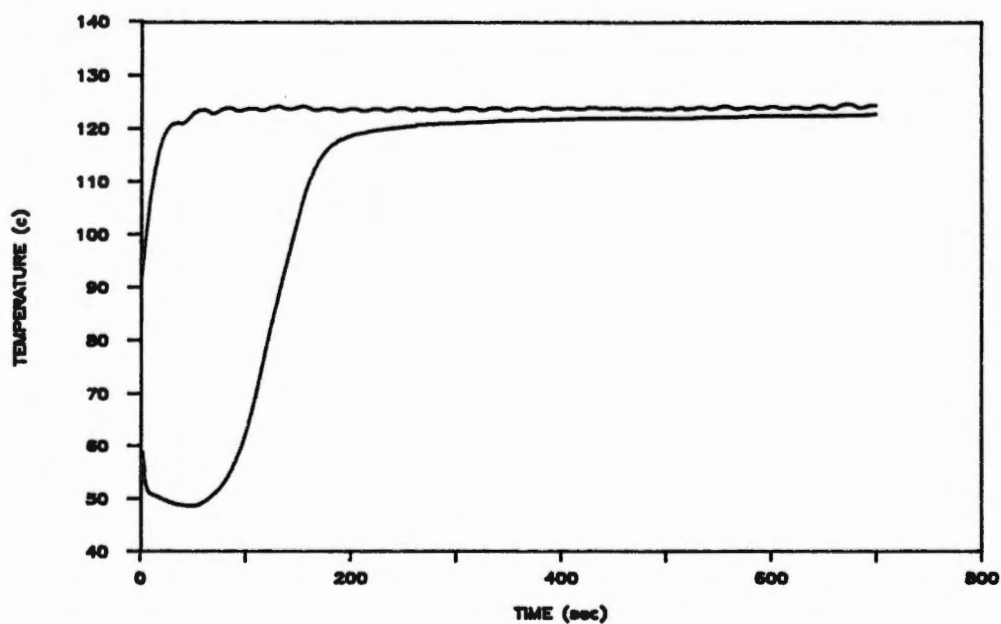


FIGURE C-14. Temperature History Curves for a 1-mm Particle Size, 76% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

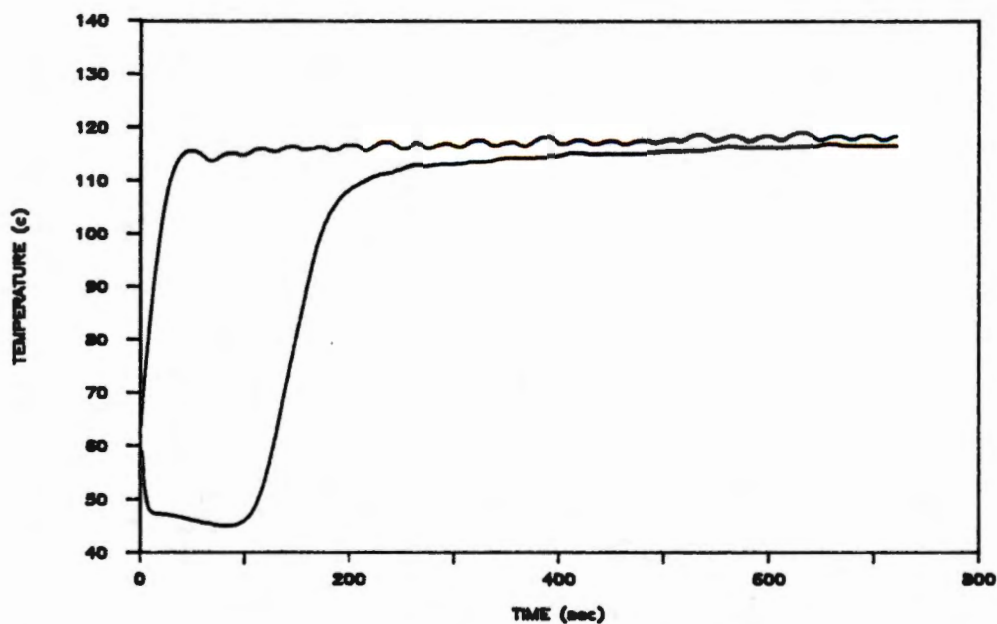


FIGURE C-15. Temperature History Curves for a 1-mm Particle Size, 88% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

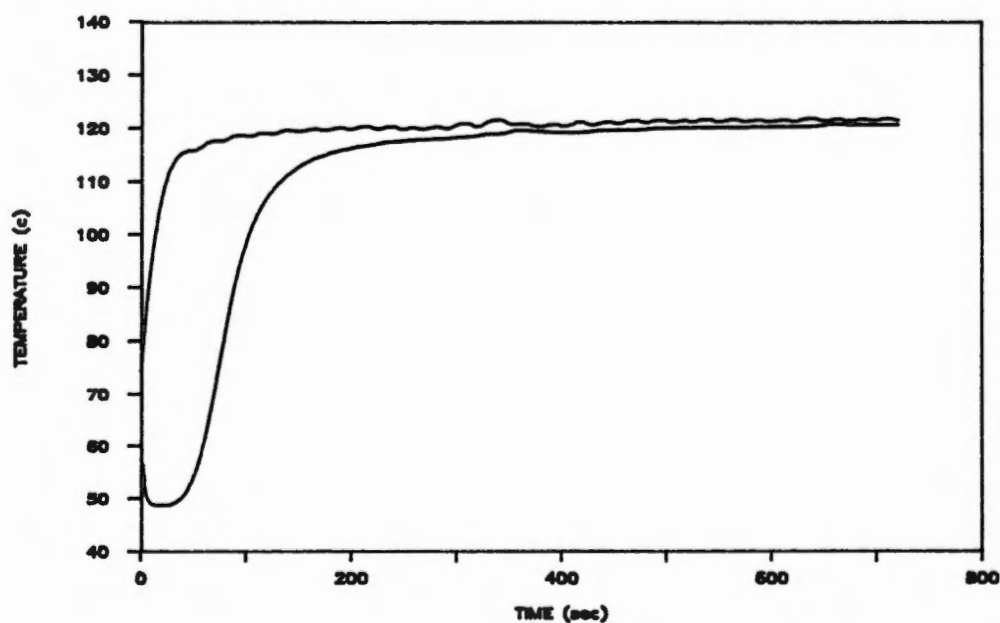


FIGURE C-16. Temperature History Curves for a 3-mm Particle Size, 58% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

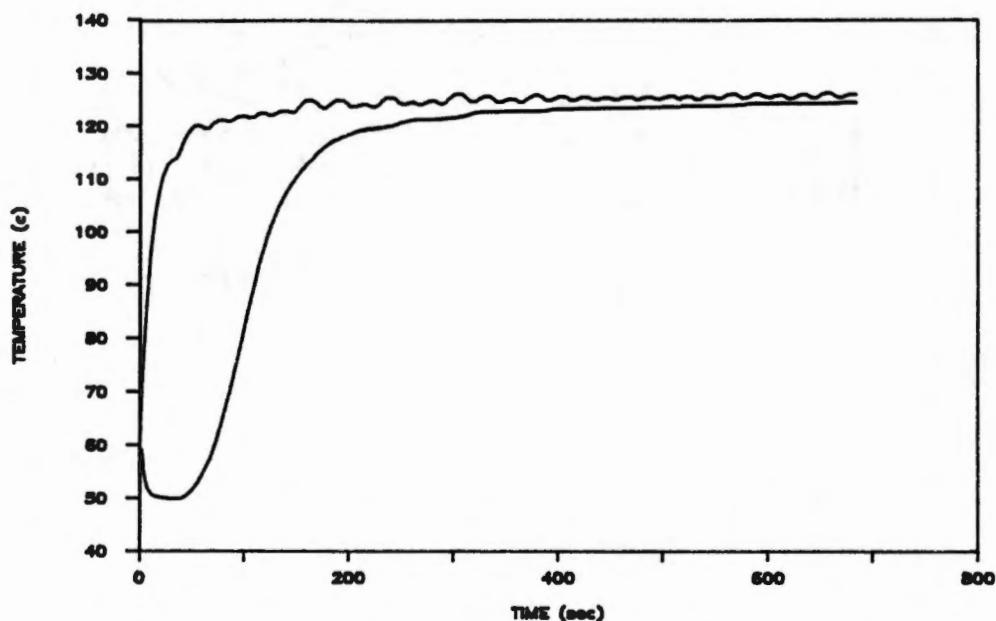


FIGURE C-17. Temperature History Curves for a 3-mm Particle Size, 76% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

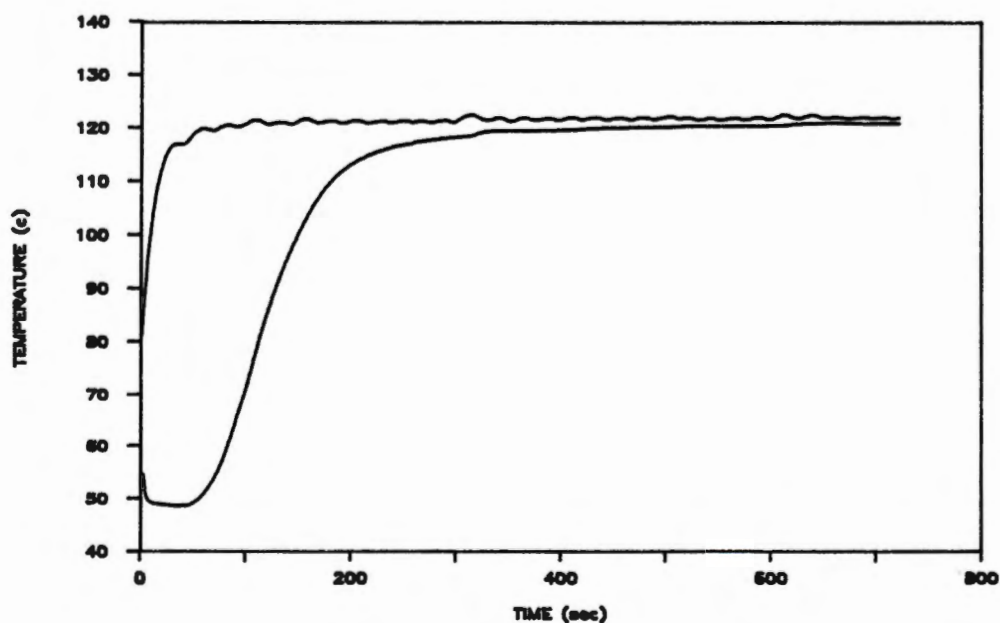


FIGURE C-18. Temperature History Curves for a 3-mm Particle Size, 88% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

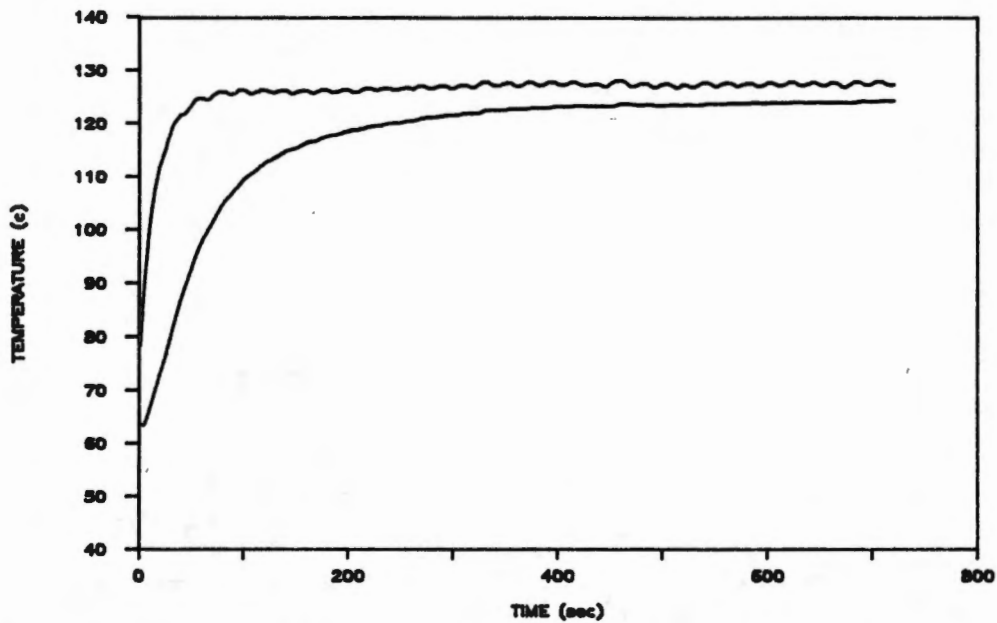


FIGURE C-19. Temperature History Curves for a 6-mm Shred Size, 58% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

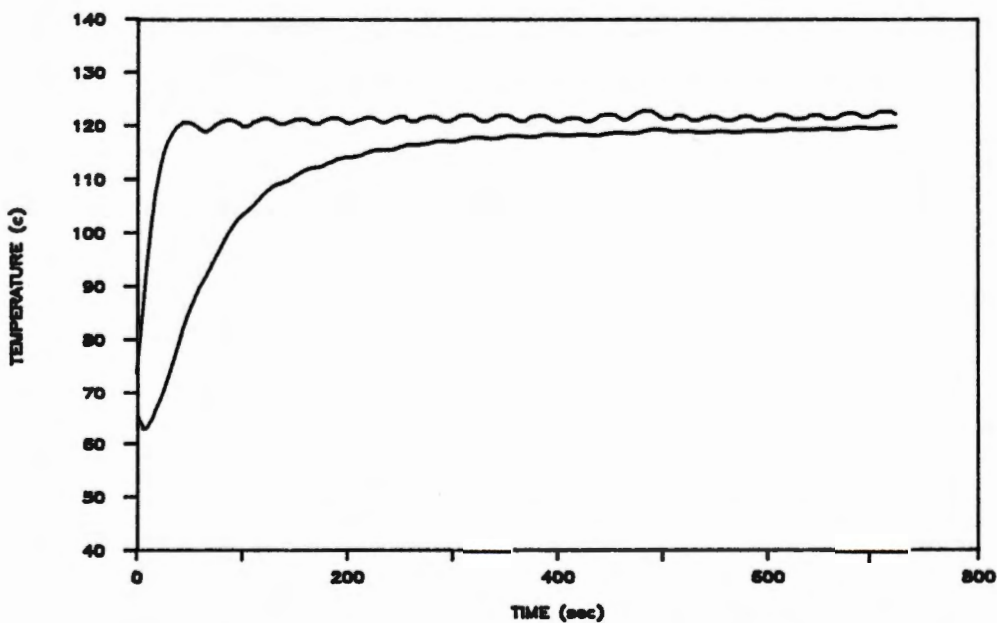


FIGURE C-20. Temperature History Curves for a 6-mm Shred Size, 76% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

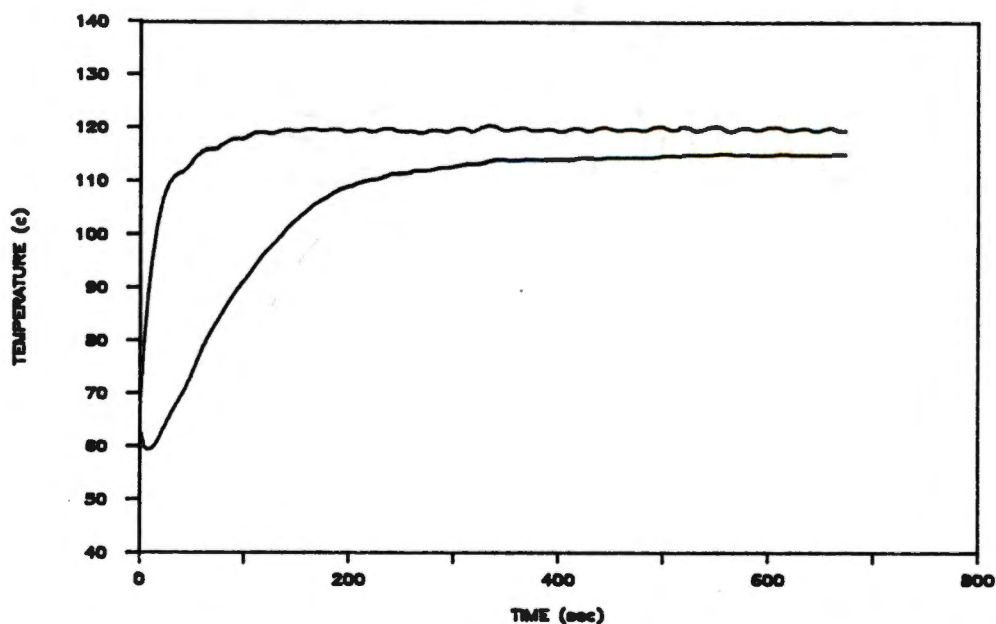


FIGURE C-21. Temperature History Curves for a 6-mm Shred Size, 88% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

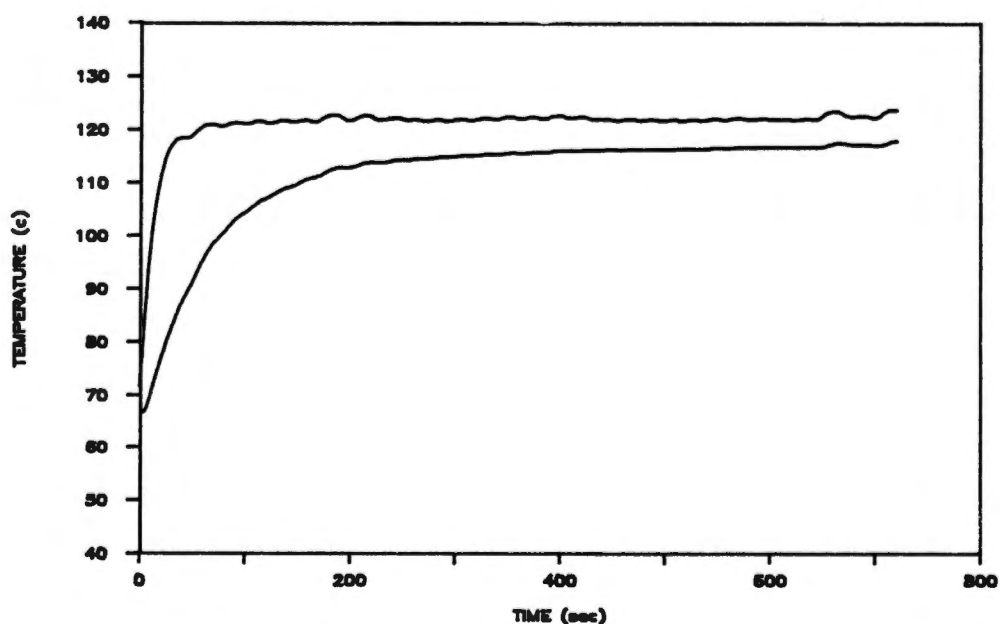


FIGURE C-22. Temperature History Curves for a 25-mm Shred Size, 58% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

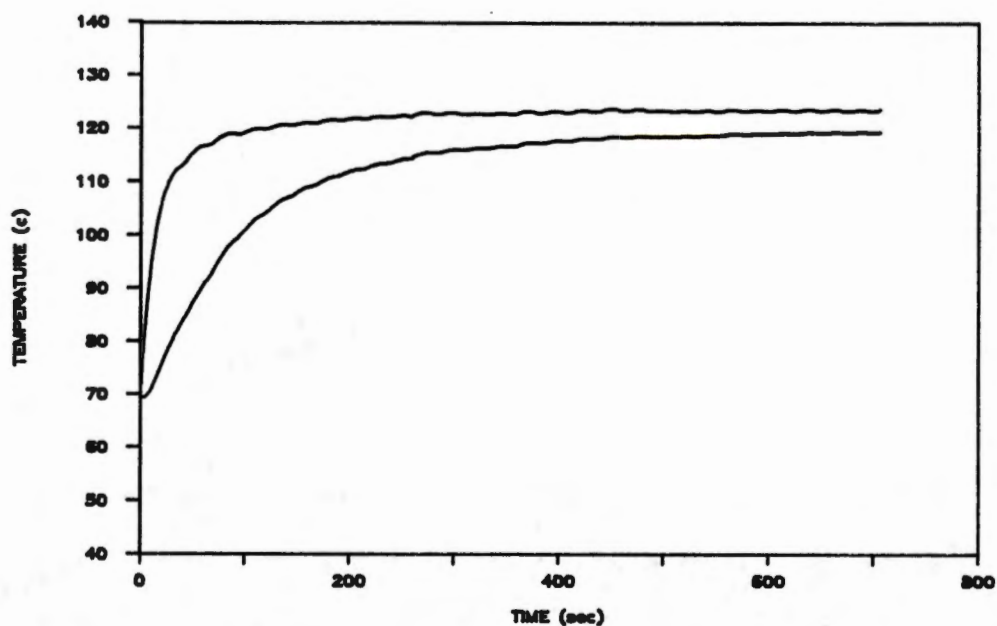


FIGURE C-23. Temperature History Curves for a 25-mm Shred Size, 76% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

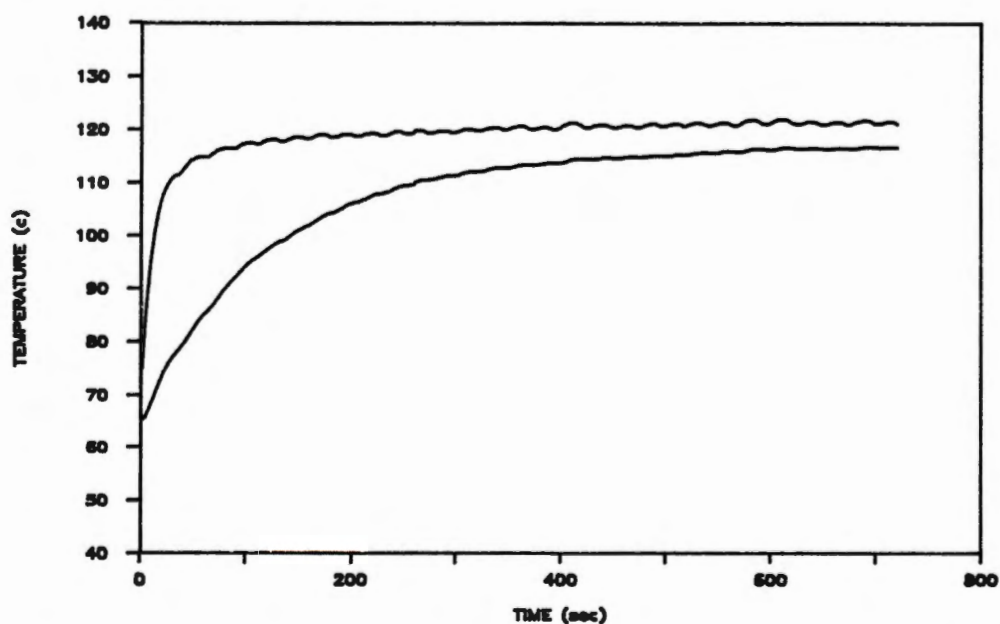


FIGURE C-24. Temperature History Curves for a 25-mm Shred Size, 88% RH Conditioned, Top Stalk Position Burley Sample. Inlet Temperature is the Top and Exit Temperature the Bottom Line.

VITA

William Mickel Davis was born in Maryville, Tennessee on January 15, 1957, the son of Mr. and Mrs. William A. Davis. He attended both elementary and high schools in Townsend, Tennessee and graduated in 1975. He enlisted in the United States Navy in 1977 where he served two years and completed the Nuclear Power Training Program.

He began his undergraduate program in 1978 as a part-time evening school student while working for the Tennessee Department of Transportation, and in June, 1986, received a Bachelor of Science degree in Agricultural Engineering. Supported by an assistantship funded by the R. J. Reynolds Tobacco Company, he began a full time study toward the Master of Science degree in Agricultural Engineering in September, 1986. He is a student member of the American Society of Agricultural Engineers and the American Society of Heating, Refrigeration and Air Conditioning Engineers. He is also a member of Gamma Sigma Delta and the Order of the Engineer.

He is married to the former Regina Rose Huskey of Sevierville, Tennessee. They have four children named from oldest to youngest as Jeremiah, Shannon, Sharena, and Micah.