BLUESTEM GRASS SEED DRYING PROPERTIES

By

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PREFACE

This study was concerned with development of the drying properties of bluestem grass seed in order to provide data on requirements necessary for the construction of dryer equipment. The primary objectives were to determine the resistance to airflow of the seed and to develop equilibrium moisture curves for the seed.

The author wishes to extend sincere thanks to her major adviser Dr. Gerald Brusewitz for his patience, guidance and friendship throughout the entire course of study. Appreciation is also to given to Dr. Richard Whitney for his help in obtaining seed samples and background information in addition to serving on the advisory committee. A special thank you to Dr. Myron Paine for his encouragement and assistance in the use of the TSO facilities for the reproduction of this thesis as well as acting as a member of the advisory committee.

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And finally, to my husband Dave and children, Chantelle and Andrew, whose love, patience, encouragement and help made this entire study possible, this thesis is dedicated.

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LIST OF SYMBOLS

a	= product constant, eqn 1
A	= product constant, eqn 8
b	= product constant, eqn 1
B	= product constant, eqn 13
BDD	= bulk density, dry basis, g dry matter/cm**3
BDW	= bulk density, wet basis, g dry matter/cm**3
c	= product constant, eqn 5
C	= product constant, eqn 15
c_1, c_2, etc.	= product constants, eqn 6
d	= equivalent particle diameter, ft.
d.b.	= dry basis
D	= bed depth, m.
EMC	= Equilibrium Moisture Content, % dry basis
exp	= exponent to the base of the natural logarithm
F	= variance ratio
g	= conversion factor, lbm ft/lbf sec**2
h	= bed height, ft
k_m	= product constant, dimensionless
k_4, k_6	= product constants,eqn 3
k	= product constant, eqn 6

K	=	product constant, eqn 14
m.c.	=	moisture content, % dry basis
M_e	=	EMC, % dry basis
n	=	product constant, Eqn 5
OSL	=	Observed Significance Level
P	=	pressure drop, cm of water
Q	=	airflow rate cfm/ft**2
R Square	=	coefficient of determination
rh	=	relative humidity, %
std dev	=	standard deviation
T	=	temperature, C
T(abs)	=	temperature, R
u	=	superficial air velocity, ft/min
v	=	superficial air velocity, m/sec
x_1	=	log of vapor pressure of pure water
x_2	=	seed moisture content, % dry basis
Y	=	log of vapor pressure of seed moisture
ρ	=	air density, lb/ft**3
ϵ	=	porosity, dimensionless

CHAPTER I

INTRODUCTION

Plains is a chaffy-seeded Old World Bluestem grass with several qualities which make it suitable for growth in semiarid climates such as that found in Western Oklahoma and adjacent states. This strain is resistant to drought and to certain rust organisms which can severely damage other grass varieties. Another positive feature is its ability to thrive on a wide range of soil types (Ahring, 1978). In addition, plains bluestem is a winter-hardy grass which can be grazed from May into the late fall. Because plains bluestem combines these aggressive and persistent qualities with good productivity, it has the potential to be used for vegetative cover in depleted rangelands either as a pasture grass or as a conservation cover (Taliaferro, 1972).

Scarcity of the seed due to poor harvest efficiencies and lack of processing equipment has limited the widespread use of this grass. However, recently an improved mechanical harvester has been developed at Oklahoma State University (Whitney, 1978) which is expected to increase the availability of the seed. Larger seed harvests will, in turn, increase the demand for improved drying methods. To date, the most prevalent method of drying harvested seed has been to spread the seed on tarpaulins, sheets, plastic film, or barn floors in a layer 8 to 12 inches (20-30 cm) deep, followed by regular stirring until dry (Ahring, 1978). Another drying technique commonly used is to collect the seed in burlap bags and allow them to sit in the open, turning occassionally to promote uniformity (Whitney, 1978).

These methods have proved to be unsatisfactory especially during periods of high humidity and/or cool weather, when the need for artificial drying becomes a necessity.

Some artificial drying of this seed is done in barns with false floors (Ahring, 1978). Since there is no information available on drying properties of bluestem, drying systems in use have not been specifically designed for this purpose and are, therefore, not necessarily efficient.

In general, airflow resistances of agricultural products have been found to be affected by their moisture content, by the presence of foreign particles and by the degree of packing in the bed. Because harvested bluestem seed usually contains a large amount of leaves and stalks, the percentage of foreign matter could affect airflow. The degree of packing is important since the seed is characteristically light and fluffy. It can be very loosely packed in a bin or very densely packed from settling. Since one proposed dryer design (Whitney, 1978) incorporates a portable bin which is loaded in the field and hauled to the drying site, some settling of the seed could occur in transport.

Equilibrium moisture content is an important property in both storage and drying. The product moisture content is affected by both ambient air temperature and humidity. Knowledge of the relationship between moisture content and air relative humidity relationship is necessary to insure viability of the seed during drying storage.

The objectives of this thesis were to determine:

1. The airflow resistance of bluestem grass seed as affected by bulk density, purity and moisture content.

2. The equilibrium moisture of bluestem grass seed as affected by seed purity and air temperature.

CHAPTER II

LITERATURE REVIEW

Resistance to Airflow

Forced air drying through a stationary bed of seed is characterized by a static pressure drop due to friction losses. The relationship between static pressure drop and airflow has been experimentally determined for many different grains and other seeds. Henderson (1944) investigated this relationship for beds of soybeans and oats. For the soybean data, a log-log plot of airflow (cubic feet per sq ft min) versus air pressure (inches of water) was best fitted by the relationship:

$$Q = 67(P^{**}0.643)/(D^{**}0.57) \qquad (1)$$

in which:

Q = airflow rate, cubic ft per sq ft min

P = pressure drop, inches of water

D = depth of grain, feet.

Since the airflow versus air pressure data for oats was nonlinear, no attempt was made to fit it with a linear equation.

Shedd (1953) studied relationships of airflow versus pressure drop for a number of seeds including wheat, shelled corn, alfalfa, fescue and others. The resultant log-log plots of airflow (in cfm/sq ft) vs. pressure drop (in inches of water) per foot depth of grain have been adopted as Standard D272 by the American Society of Agricultural Engineers (ASAEa, 1979). The curves tend to be slightly convex upward. The series of curves (one for each product) represents experimentally determined averages for clean, loosely filled and relatively dry material. The curves can be represented by the general formula:

$$Q = a(P^{**}b) \qquad (2)$$

where:

Q = airflow, cu ft per min per sq ft of floor

P = pressure drop per ft depth of grain, in of water

a and b = constants for any one lot and condition of grain

a = the value of Q when P=1

b = the slope of the curve on the chart.

In general, the slope b of the curve increases with the fineness of the material. However, values of a and b remain constant for a narrow range only because of the convexity of the curve thus limiting the usefulness of the formula.

According to Shedd (1953) the effect of the percent of foreign matter was dependent on its texture, with increased resistance from added fines and decreased resistance with blends containing coarser materials. In addition, high-moisture grain (20% w.b. or higher) was found to have less resistance than that of the same sample at a lower moisture content. He also noted that a packed bed of grain has a higher resistance to airflow than does a loosely packed bin. Because of the reduction in particle size as drying occurs, however, an undisturbed bed which is initially tightly packed can become less resistant to airflow at lower moisture contents.

Sheldon (1961) found that at low airflow (0.5-4.0 cfm/ft**2; 0.0025-0.02 m**3/sec/m**2) resistance through shelled corn and wheat increases more rapidly than the depth of grain. Resistance to airflow similarly increased more rapidly than does the increase in airflow. A log-log plot similar to Shedd's data produced a convex curve which was divided into three parts representing the laminar, transition and turbulent ranges of flow. The laminar zone can be described by the formula:

$$\log(P) = \log(k_4) + \log(V) \tag{3}$$

and the turbulent region by:

$$\log(P) = \log(k_6) + 2\log(V) \tag{4}$$

where P represents the pressure drop and V the airflow, with k_4 and k_6 the respective constants.

Moisture content of pumpkin seeds was found to be an important factor in airflow resistance by Akritidis and Siatras (1978). This effect was attributed to low moisture kernels being smooth and, therefore, producing a lower friction loss. Five different moisture contents produced parallel convex curves with plots similar to those of Shedd.

Bakker-Arkema et al. (1969) studied the effect of packing on the airflow through a bed of cherry pits. Porosity of the bed was used as a measure of packing. They proposed two dimensionless parameters as a more universal representation of resistance to airflow. The dimensionless quantities selected were: $(P/h)(gd/\rho(u^{**}2)k_m)\epsilon^{**}3/(1-\epsilon)$ versus $Re/(1-\epsilon)$ where:

P = pressure drop, in. water

h = bed height, ft

g = conversion factor, lbm ft/lbf sec**2

d = equivalent particle diameter, ft

ρ = air density lb/ft**3

u = superficial air velocity

k_m = product constant

Re = Reynolds number, dimensionless

ϵ = porosity, dimensionless

In contrast, the standard plot of pressure drop versus airflow results in different curves for varied conditions. The nature of bluestem seed prevents measurement of these two dimensionless parameters for two reasons. First, the high percentage of leaf and stem mixed with the seed creates an obstacle in determination of an equivalent particle diameter since these impurities are so dissimilar to the seed itself. The fluffy nature of the dried seed would also make it difficult to determine its porosity.

Equilibrium Moisture Content

Seeds contain adsorbed moisture which varies with the relative humidity and temperature of the air. Brooker et al. (1974) define equilibrium moisture content (EMC) as "moisture content of the material after it has been exposed to a particular environment for an infinitely long period of time". The adsorption (or desorption) of water by the seed is due to the difference between the vapor pressure of the water held by the seed and that of the water vapor in the air. If the water contained in a seed exerts a vapor pressure lower than that of the surrounding air, the seed will adsorb water from the air and continue to do so until an equilibrium is reached. The converse is also true.

Because EMC is so important in the drying and storage of grains, equilibrium moistures have been determined for many different agricultural products. Standard D245.2 in the ASAE Yearbook contains EMC data on a number of seeds (ASAEb, 1979). A plot of equilibrium relative humidity (ratio of moisture vapor pressure to that of the saturation vapor pressure of pure water at the temperature of the material) versus EMC is called the equilibrium moisture curve. This curve is also referred to as an equilibrium isotherm since temperature is constant. The curves are characteristically sigmoid (S-shaped) type curves and tend to rise sharply above 85% relative humidity (Brooker et al., 1974).

One equation which can be used to define the equilibrium moisture curve was proposed by Henderson (1952):

$$(1-rh) = \exp[-cT(M_e**n)] \quad (5)$$

where:

rh = relative humidity in decimal form

M_e = EMC, dry basis as a percentage

T = temperature, ^{o}R

c, n = product constants

Although actual data points cannot always be fitted exactly by an equation of this form, it does have the following features:

1) The equilibrium moisture content is zero at zero relative humidity.

2) The equilibrium relative humidity approaches 100 percent as the moisture approaches infinity.

3) The slope of the curve approaches infinity and increases rapidly as the moisture content approaches zero.

Haynes (1961) tested the following seeds for EMC: lupine, crimson clover, rescue, fescue, wheat, corn and sorghum. He developed the following equation to describe the equilibrium of the different seeds:

$$Y = k + c_1x_1 + c_2x_2 + c_3x_1**2 + c_4x_1x_2 \quad (6)$$

in which

Y = the log of the vapor pressure of seed moisture

x_1 = the log of the vapor pressure of pure water at test temperature

x_2 = the seed moisture content, percent dry basis

k, c_1, c_2, c_3 and c_4 = product constants.

The plot of Y versus x_2 yields a straight line on log-log paper. Using this equation all seed species except fescue produced high correlation coefficients. Although the regression coefficient for rescue was high, curves for different temperatures intersected and crossed indicating a temperature inversion effect. One possible explanation for the erratic readings is that the seeds retain outer husks during processing and storage and these husks represent a high proportion of the total weight and volume of the material tested. Since bluestem seed also has this tendency, this equation would not be appropriate.

An equation developed by Chung and Pfost (1967) to describe EMC is based on adsorption potential theory with modified assumptions and thermodynamic relationships incorporated. The resulting equation is as follows:

$$\ln(p/p_0) = -(A/RT)(\exp(-BM_e)) \qquad (7)$$

where:

p/p_0 = relative humidity expressed as a decimal

A and B = constants specific for product and temperature

R = ideal gas constant

T = Temperature, absolute $^{\circ}$R

M_e = Equilibrium moisture content, % dry basis

This equation was purported to fit data for grain EMC in the 20-90% range for corn, corn starch, corn hull, corn gluten, corn germ and wheat.

Brooker et al. (1974) lists several other theoretical and semi-theoretical equations formulated by various researchers to describe the relationship between EMC and relative humidity but none of these is adaptable to the full range of relative humidities and temperatures commonly encountered. Therefore, these are not practical.

According to Hall (1957) the adsorption of moisture is determined by the composition of the product, and the equilibrium moisture curve is influenced by the relative amounts of carbohydrate and protein present. Lamour et al. (1944) noted the influence of oil and ash content on the hygroscopic nature of seeds.

In order to determine the EMC for a given humidity and temperature, the seed must be placed in the environment until equilibrium is reached. There are two ways to achieve a constant relative humidity: (1) the static method and (2) the dynamic method (Brooker et al., 1974). With the static method the seed is placed in still, moist air at constant temperature and allowed to come to equilibrium. In the dynamic method the air is circulated mechanically.

When the static method is used, there are several ways to control the humidity. Aqueous solutions of sulfuric acid, HCl and KOH at various concentrations affect the vapor pressure of the air above them (Stokes and Robinson, 1949; Buxton and Mellanby, 1934). These solutions are not easily used because of the potential danger during handling. However, saturated salt solutions can also be employed. Various salts produce unique relative humidities and proper selection of a variety of salts can be used to produce a wide range of relative humidities. Several researchers have listed the relative humidity produced by numerous salts at several temperatures (Hall, 1957; Wink, 1946; Carr and Harris, 1949; Stokes and Robinson, 1949). Some of these are listed in Table I .

There are several mechanical systems available for use in the dynamic method. One such device is an environmental chamber control which regulates both temperature and relative humidity.

It is generally agreed that the EMC obtained for relative humidity greater than 85% is not a true one for the product because of the growth of molds (Hall, 1957; Brooker et al., 1974). This is especially true when the static method is employed since longer periods are required to reach equilibrium.

The EMC reached by dry seed is not always the same as the EMC achieved by the same seed at a higher initial moisture content placed in the same atmosphere. The difference between the adsorption EMC and the desorption EMC is known as the hysteresis effect (Brooker et al., 1974).

TABLE I

RELATIVE HUMIDITY OF SEVEN SALT SOLUTIONS

		Relative Humidity in %				
Number	Salt	Hall (20C)	Carr (30C)	Wink (23C)	Buxton (20C)	Stokes (25C)
1	Potassium Acetate	23.2	-	22.9	20	22.5
2	Potassium Carbonate	43.9	-	43.9	44.0	42.8
3	Sodium Dichromate	55.2	54.2	54.1	-	-
4	Sodium Nitrite	65.3	63.0	64.8	-	-
5	Sodium Chloride	75.5	75.7'	75.5	78.3	75.3
6	Potassium Chromate	86.6	-	86.5	-	-
7	Ammonium Monophosphate	93.2	-	92.9	-	-

'21C

Pixton and Warbarton (1975) found that addition of the mold retardant, propylene oxide, affected the desorption patterns of wheat, producing a reverse hysteresis effect. They also showed that the extent of hysteresis on untreated wheat is influenced by experimental technique. When separate samples were exposed to different relative humidities, the desorption isotherm was displaced to the left with a relatively high hysteresis. This effect was reduced markedly when stepwise reduction of moisture content of the sample was achieved, allowing equilibrium to take place at each step.

CHAPTER III

APPARATUS AND PROCEDURE

Resistance to Airflow

A rectangular bin, 30.4x28.2x60.0 cm, fitted with a perforated bottom made of wire screen (6.5 openings/cm), was set on a box containing a 100 watt (0.1 HP) squirrel cage fan. The fan was connected to a Staco Variable Auto-transformer with a voltage range of 0-140 volts to allow regulation of airflow rate. A Dwyer Magnehelic pressure gauge with a range of 0-2 cm water was attached to a port located near the airflow entrance. The top of the bin was fitted with a gradually decreasing cross-section transition duct connected to a long duct measuring 9.2 x 9.2 x 88.9 cm. (Figure 1). This addition enabled the reading of low airflow rates through the seed. An 'egg carton' type flow divider was placed in the entrance to the long duct to develop laminar flow in the duct.

Superficial air velocity was measured with a hot wire anemometer (Thermosystems, Model 1650) which was first calibrated with a pitot tube attached to a micromanometer. The pitot tube was inserted in the same duct used for the airflow tests and the velocity head read from the micromanometer. Average velocity was determined

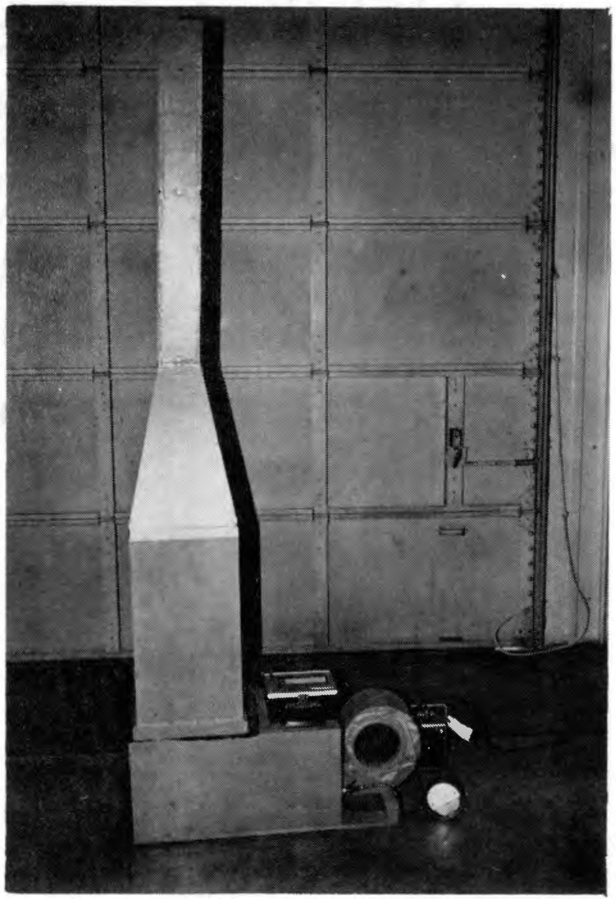


Figure 1. Apparatus for Airflow Resistance Measurement

simultaneously by traversing the cross-section at 1.0 cm intervals in the duct and averaging the readings. When the value coincided with the velocity measured at a specific location, the hotwire anemometer probe was marked for future use.

Freshly harvested seed was first sampled for moisture content. Moisture content was determined by drying 4-6 randomly selected samples of approximately 50 g each in a 100C (+/- 2C) electric oven for 24 hours. ASAE Standard 352 recommends a drying time of only one hour for bluestem grass seed. Since these samples contained over 50% leaves and stems, the drying time and temperature for forage moisture contents was used instead. (ASAEc Yearbook, 1979). After placing a sample in the oven and weighing it at the end of 1, 2, 12, 24 and 48 hours it was decided that one hour was insufficient time. A Saratorius top loading balance was used to weigh samples to within 0.01 g. Moisture was computed on a dry basis.

After moisture content samples were taken, a 2-4 kg sample of seed was placed in a plastic bag and weighed on a Toledo scale to within 0.1 kg. The seed was then loosely packed by hand into the bin to a predetermined depth. After the long duct was attached to the bin and sealed with duct tape, the airflow was adjusted until a pressure drop of nearly 2 cm of water, the full-scale reading, had developed. The hot wire anemometer probe was inserted into the duct and held in place until the reading stabilized (30-60 sec). The hole into which the probe was placed was 78 cm from the entrance to the duct, sufficiently far from the point where flow had originated to insure the development of laminar flow. After pressure and velocity readings were recorded, air flow was decreased by a 10 volt reduction in the voltage regulator. This procedure was repeated with the 10 volt increment reductions until a pressure drop near zero was reached.

Next, seed was tamped in the bin until a reduction in volume of approximately 25% was achieved and the procedure was repeated. The entire modus operandi was repeated four times at increasing bulk densities.

After the pressure drop-airflow experiment the seed was placed in burlap bags for drying. The sacks of seed were left at room conditions and turned several times a day. After the seed was dried, samples were taken to determine the moisture content and the airflow resistance tests repeated. The same series of tests was run with seed harvested on July 6, October 11 and October 21.

Pressure drop due to the apparatus was determined by measuring the pressure drop at the same range of velocities in an empty bin. Appropriate adjustments were subsequently made to the total running resistances to determine the resistance of only the seed.

Samples of the dry seed were taken to the Oklahoma State University Agronomy laboratory where seed purity was determined using the method of Harlan (1960).

Equilibrium Moisture Content

Static Method

To determine EMC of bluestem grass seed, using the static method, the use of saturated salt solutions to control the humidity was employed. The salts listed in Table I were selected from Hall's (1957) data on relative humidity of saturated salt solutions to provide a range of relative humidities between 22.5 and 93.9% at 20C. Values available from other sources are also listed as an endorsement to the accuracy of the figures and in some cases to demonstrate the effect of temperature on the humidity produced by the salt.

The saturated salt solutions were prepared by taking an amount of salt in excess of that required for saturation at 20C. The salt was added to distilled water and heated moderately with a hot plate magnetic stirrer. Saturation was insured by allowing some undissolved salt to remain with the solution, adding more when necessary. Two hundred fifty ml of each solution were placed in an airtight 4600 ml plastic container which measured 32 x 18 x 8 cm.

Approximately 25 g of seed were placed in a basket with dimensions circa 16 x 20 x 3 cm, constructed of fine stainless steel mesh (16 openings/cm). Polyvinyl chloride rings 3-4 cm high were set in the solutions to hold the baskets above the liquid. This arrangement is shown in Figure 2.

Figure 2. Baskets of Seed Suspended Over Salt Solutions

The tightly closed containers were held at constant temperature (20C) in a low-temperature incubator.

Preliminary tests were run with sodium chloride (NaCl) solutions to determine sufficient residence time to reach equilibrium. Six replicates were placed in the NaCl atmosphere and at the end of 2 day, 5 day and 7 day periods, two each were removed and samples dried for moisture determination. Since the seed appeared to be continuing to adsorb moisture after 1 week, an additional test was repeated for 2 weeks and 3 weeks. The average moisture content at the end of both of these periods was the same (14.1%); thus, two weeks was chosen as the optimal time.

After this time requirement was established, tests were run with 3 replicates using solutions of salt numbers 1, 2, 5 and 7 as listed in Table I . These initial tests included seed from the June, July and first October harvests. The analysis was performed on the freshly harvested seed and then repeated with dried seed from each of these harvests.

Solutions of the remaining salts listed in Table I were added for the testing of the seed from the final harvest (October 21). Lack of space in the incubator limited the number of samples; therefore, only two replications were run at each relative humidity. The same procedures as used in the initial investigation were used to determine the EMC curve for the seed from this harvest.

Randomized Block Design

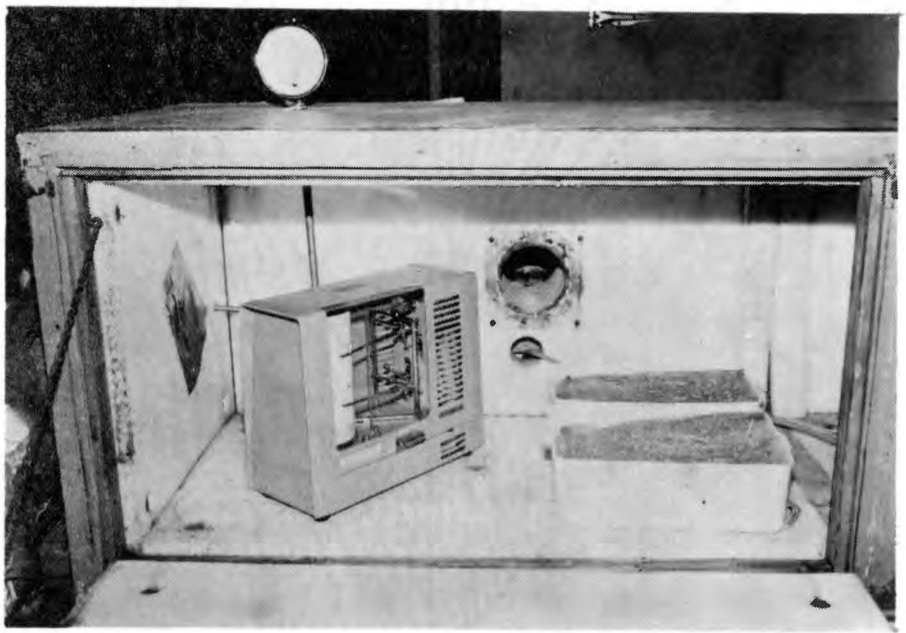
The dried seed from the earlier harvests along with some higher purity seed stored from past years was retested to include data at the additional relative humidities to complete a randomized block design for the determination of the effect of purity on EMC. The statistical design could thus be summed by: EMC = f(rh, Purity) with rh representing fixed treatments and Purity random blocks. The treatments were thus 43.9, 55.2, 65.3, 75.5, 86.6 and 93.2% relative humidity at four different purities. There were two replicates of each purity at each relative humidity for a total of 20 samples for the analysis of variance.

Dynamic Method

The environment chamber used is shown in Figure 3. The chamber consists of a wooden rectangular box insulated with 2.5 cm of styrofoam. Attached to the chamber is the Aminco-Aire control unit which supplies conditioned air with controlled humidity and temperature with a fan. The relative humidity is governed by drawing air from the chamber through a fine water spray at the dew point temperature. The air is then heated in the adjoining compartment of the control unit by an electric heater to the desired dry bulb temperature before returning to the chamber. A hygrothermograph was kept in the environment chamber to monitor in temperature and relative humidity. A dry bulb thermometer with graduations of 2 degree F was inserted in the side and could be read without opening the chamber. A Quiktest hair hygrometer was inserted in the top to provide an approximate reading of relative humidity inside the closed chamber. Precise relative humidity was periodically measured with an aspirator psychrometer (Psychro-Dyne Model CP 147, Environmental Tectonics Corp.) which had been calibrated against a sling psychrometer.

Dry bulb temperature was kept constant at 90 +/- 2 F and the water temperature was varied to produce a range of humidities from 18 to 92%.

Approximately 50 g of fresh seed samples were placed in bags made of nylon mesh (6.5 openings/cm). The bags were set on polyvinyl chloride rings in open plastic containers identical to those used in the static testing procedure. The open container was covered with a doubled layer of the nylon mesh to prevent the fine seed from being blown out. Weighings were taken of the tare weights and then with the seed on the Saratorius balance. Four replicates were placed in the chamber at high humidity and allowed to come to equilibrium. Weighings were made every 12-24 hours with the container temporarily covered immediately upon removal from the chamber. After a stable weight was observed, water temperature was readjusted to lower relative humidity inside the chamber approximately 10%. This procedure was repeated until the seed had been exposed to relative humidities ranging from approximately 90 to 20%. After final equilibrium



was attained a sample was taken from each container and dried to determine the final moisture content and also the weight of dry matter present in the total sample. The above procedure was repeated with dry seed, beginning the test at the lower end of the humidity range and increasing relative humidity in 10% increments thereafter.

CHAPTER IV

RESULTS AND DISCUSSION

Resistance to Airflow

Regression Analysis of Airflow Resistance Data

The equation developed by Shedd (Eqn. 2) to describe the relationship between airflow and pressure drop in a bed of seed or grain can be rewritten in the form:

$$\text{Log}(Q) = A + b(\text{Log } P) \tag{8}$$

where $A = \log a$

Since bulk density, moisture content and purity were of interest in the investigation of the appropriateness of this equation, the data were sorted by bulk density and moisture content. Each group of data was then fitted to the model using the regression analysis procedure General Linear Model (GLM) of the Statistical Analysis Computer Package (Barr et al., 1976).

Bulk density of the material in the bed can be calculated in two ways. First, total weight divided by volume gives a bulk density based on total matter present which will hereafter be referred to as wet basis bulk density (BDW). An alternative classification can be dry basis bulk density (BDD) which is calculated on the basis of dry matter only. This dry basis bulk density would seem to be a more uniform classification since the bulk density term is really a way to define void spaces in the bed; in addition, moisture in the material contributes more in additional weight than it does to volume. However, since precise moisture content may not be known at the time of drying, it is useful to include an analysis by wet basis bulk density also. Seed tested included a range of BDW from 0.05-0.12 g/cm**3 with moisture content varying from 17.5 to 78.6%. The range of dry matter bulk densities was 0.035-0.074 g/cm**3.

When the data characterized by BDW was analyzed, R Square values tended to be above 0.9. The lowest value of R Square was 0.526 for BDW = 0.05. This set of data was the only set which included data from a run with dry seed and one with fresh seed. The significance of this will become apparent in later discussion. When data was regrouped according to BDD, R Square values tended to be higher. Table II lists these R Square values along with predicted values for A and b. Using these predicted constants, superficial velocity was then calculated based on the observed pressure drops.

Table XI, listed in Appendix A, is the data for calculated velocities, the corresponding experimental velocities, the difference between calculated and

TABLE II

SUMMARY OF REGRESSION DATA BY BULK DENSITY

BDD g/cm**3	BDW g/cm**3	Harvest	%m.c.	R Square	A	b	no. of obs.
			Based on Dry Matter				
0.035	0.05	July 6	42.6	0.994	-1.51	0.61	9
0.043	0.05	Oct. 21	17.5	0.930	-1.75	0.58	12
0.045	0.08	Oct.11	78.6	0.979	-1.78	0.61	6
0.054	0.08 & 0.096	Oct.21 Oct.11	47.8	0.953	-1.79	0.63	24
0.063	0.09	July 6	42.6	0.984	-1.90	0.62	6
0.067	0.12	Oct.11	78.6	0.905	-1.65	0.47	16
0.074	0.11	Oct.21	47.8	0.837	-1.86	0.52	7
			Based on Total Matter				
0.035& 0.043	0.05	July 6 Oct.21	42.6	0.526	-1.24	0.39	21
0.045& 0.054	0.08	Oct.11	78.6	0.943	-1.75	0.61	23

experimental readings and the percentage error of the calculated value. The calculations in the first part of the table are based on the constants derived from the analysis of the BDD data; and in the second part of the table, BDW data was used in the analysis.

For the most part, data based on BDD comes from one harvest at one moisture content and therefore represents only one bulk density, wet basis. However, at BDD = 0.054, two different harvests of seed (Oct. 11 and Oct. 21) which contained moistures of 78.6 and 47.8% ,respectively, are at this same BDD. This particular analysis, therefore, represents two different wet basis bulk densities (0.08 and 0.096). Despite this difference, the R Square value is 0.953 and the differences between the calculated velocities and the comparable experimental values range as low as those in the groups without such differences. In contrast, at BDW = 0.05, the data includes seed of dissimilar moisture contents (17.5 and 42.6%) and hence unequal dry basis bulk densities (0.035 and 0.043). As was previously noted the R Square value was much lower at 0.526 and the percentage error in the calculated velocities can be observed in Table XI . However, at BDW = 0.08 again two dissimilar moistures are included (78.6 and 47.8%) but the R Square value for this analysis is still high (R Square = 0.943). This seeming contradiction will be explained in the section on the effect of moisture content.

The Effect of Bulk Density

The effect of bulk density on airflow resistance becomes apparent when a comparison plot of seed at a range of bulk densities is made. Figure 4 demonstrates this effect at BDD = 0.035, 0.054 and 0.067 g/cm**3 in a plot similar to the standard airflow resistance log-log plot of airflow versus pressure drop, where airflow was measured by superficial velocity in m/s and pressure drop in Pa/m.

As bulk density increases, resistance also tends to increase. This total effect, which is somewhat altered at different moistures, will be discussed in the next section.

Referring to the A and b values in Table II, slopes at the various bulk densities do not appear to be directly affected by the change in bulk density. However, the intercept values appear to decrease with increased bulk density.

The increased resistance at increased bulk density would be expected since increased bulk density decreases void spaces in the bed and thus increases interference to the path of the airflow. The standard ASAE Airflow Resistance Data (D272) notes that packing can result in as much as a 50% increase in resistance (ASAEa, 1979).

The Effect of Moisture Content

The concept of dry matter bulk density versus total matter bulk density has already been discussed. The

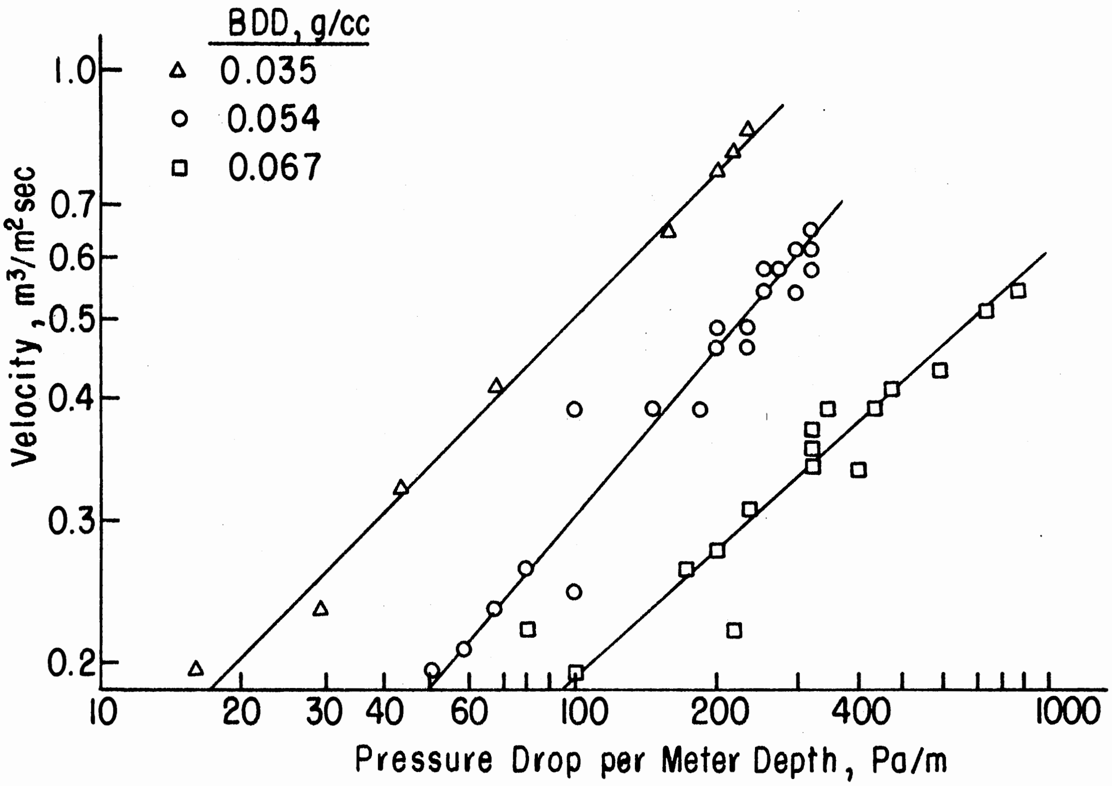


Figure 4. Resistance of Bluestem Grass Seed to Airflow for Three Bulk Densities at Three Moistures

influence of moisture content on bulk density thus partially accounts for the effect of moisture content on resistance. A comparison of seed at the same dry matter bulk density at different moistures would be useful to determine the effect of moisture content only. Such a comparison can be made at BDD = 0.054 with the data including moistures of 78.6 and 47.8%. When separate regression analyses were performed on these two data sets, the lower moisture seed analysis produced a value for A of 1.789 and for b of 0.624 while the higher moisture seed analysis resulted in an A value of 1.790 and b of 0.629. From this it would seem that moisture content alone does not greatly affect the resistance of the seed. However, although the moisture contents in this case differ by approximately 30%, the seed in both cases was freshly harvested seed and thus similar physically. Figure 5 graphically illustrates this lack of effect.

Seed which has been dried has a much different physical nature than the fresh seed with the dryer seed having a fluffier, rougher texture than the undried seed. Unfortunately data at the same dry matter bulk density is not available for both the dried seed and the undried seed. However a comparison of the dried seed at BDD = 0.043 versus the undried seed at 0.063 shows very little difference between the two despite the fact that the dried seed has a much lower bulk density and on that basis alone should offer less resistance. When seed with a comparable difference in bulk densities (0.054 versus 0.074) but at the

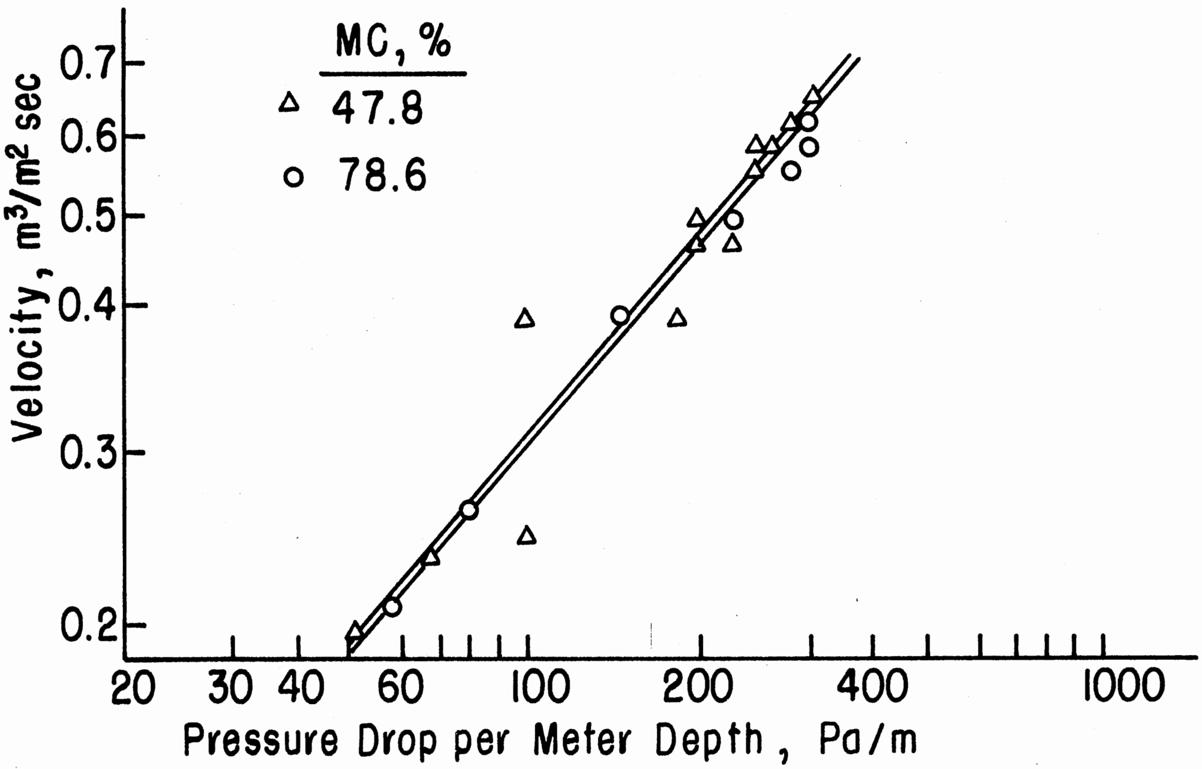


Figure 5. Resistance of Bluestem Grass Seed to Airflow for One BDD at Two Moisture Contents

same moisture (47.8%) is similarly compared, there is a noticeable difference in resistance. These four bulk densities are plotted in Figure 6 which demonstrates more evidence for increased resistance for dried seed since the line for dried seed with a BDD of 0.043 falls above that for the undried seed at a BDD of 0.054 g/cm**3.

Apparently the rougher texture of the dry seed offers additional resistance giving the looser packed dried seed as much resistance as the more tightly packed smoother undried seed. Akritidis and Siatras (1978) theorized that the rougher texture of dry pumpkin seeds contributes more reistance to air flow than the smoother surfaces of higher moisture seed and this same effect seems to occur in bluestem.

Effect of Purity on Resistance

Airflow data on freshly harvested seed was available only for the July harvest and two October harvests. The October 11 data was not useable since the seed molded during drying before the purity had been evaluated. Because of a lack of variability in the purity of the two remaining data sets (17.9 and 10.6), there was insufficient data to determine the effect of purity on freshly harvested seed. However, dried seed with higher purities (34.5 and 63.4) from previous years was available and these samples were used to test the effect of purity.

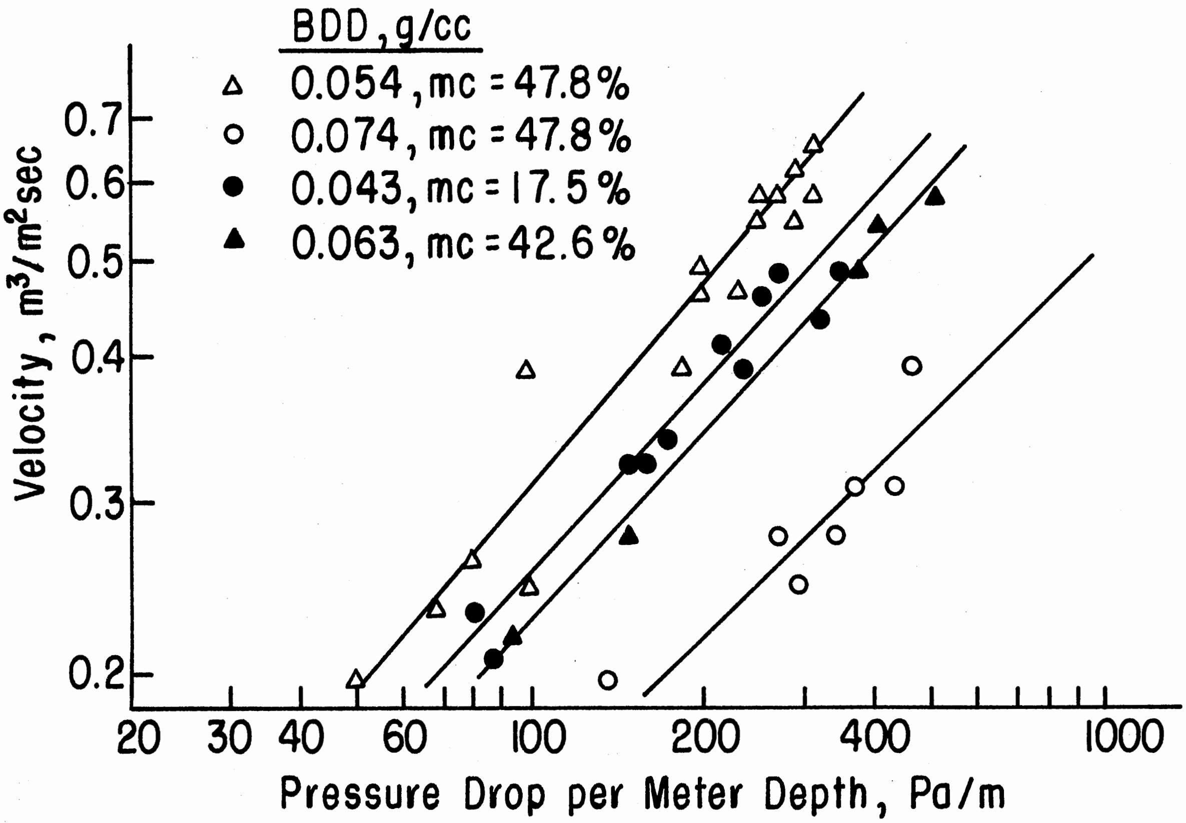


Figure 6. Resistance of Bluestem Grass Seed to Airflow for Four Bulk Densities at Three Moistures

The lowest purity dry seed available (10.6%) was tested along with the seed from the 1975 fall crop which was of the highest purity available (63.4%). The high purity seed was highly compacted at a wet basis bulk density of 0.099, with no additional packing or tamping. This was equivalent to a dry basis bulk density of over 0.09, which is considerably higher than that encountered in the earlier tests. With such a tightly packed bed, problems occurred in conducting the experiment. Since maximum fan speed produced very low air flows (measured superficial velocity of less than 2 m/s), the hot wire anemometer readings were below their range of reliability. Since all the tests were in this same low range, these values were still useful for comparison purposes. As results in Table III indicate, the lower purity seed data are nearly identical to data from higher purity seed at the same bulk density. Since moisture contents were also similar (10.2 and 13.1%), purity was the main variable and little if any effect was apparent at low air flows.

<u>Characterization of A and b Values</u>

The effects of moisture content and bulk density on the value of the constants A and b were examined by the incorporation of two Statistical Analysis System procedures (Barr et al.,1976). First the RSQUARE Procedure was applied to the constants which had resulted from the earlier

TABLE III

EFFECT OF PURITY ON AIRFLOW RESISTANCE

Purity %	Measured Vel m/s	Measured P in. water
63.4	1.5	0.85
63.4	1.4	0.80
63.4	1.35	0.75
63.4	1.2	0.70
63.4	1.1	0.65
63.4	0.90	0.50
63.4	0.60	0.30
63.4	0.25	0.125
10.6	1.4	0.85
10.6	1.4	0.80
10.6	1.3	0.75
10.6	1.2	0.70
10.6	1.1	0.65
10.6	0.9	0.50
10.6	0.6	0.3
10.6	0.25	0.125

regression analyses. The procedure was utilized to determine the R Square values for the following models:

$$A = f(MC, BDD, MC^{**}2, BDD^{**}2, MCxBDD)$$

$$b = f(MC, BDD, MC^{**}2, BDD^{**}2, MCxBDD)$$

$$A = f(MC, BDW, MC^{**}2, BDW^{**}2, MCxBDW)$$

$$b = f(MC, BDW, MC^{**}2, BDW^{**}2, MCxBDW)$$

This procedure takes every possible combination of the independent variables listed and applies a regression analysis of the relationship between the independent variables and the dependent variable then lists as output the R Square value for each analysis. This output is listed in Tables XII and XIII in Appendix B.

These same models were then used in the STEPWISE Procedure (Barr et al.,1976) which gave the following equations as the best characteristic equations for the models:

$$A = -0.69 + 0.015MC - 34.73\ BDW - 0.00019(MC^{**}2) + 141.64(BDW^{**}2) + 0.12(BDWxMC) \quad (9)$$

and

$$b = 0.21 + 11.57BDW - 78.16(BDW^{**}2) \quad (10)$$

Resulting R Square values for A and b are 0.998 and 0.911 respectively. It is interesting to note that the models chosen contained wet basis bulk density rather than dry. The STEPWISE analysis of the models containing dry basis bulk densities, on the other hand, produced equations with lower R Squares. These equations, as given below, have R Square values of 0.530 and 0.500:

$$A = -0.43 - 45.21BDD + 364.58(BDD^{**}2) \qquad (11)$$

$$b = 0.25 + 15.36(BDD) - 164.13(BDD^{**}2) \qquad (12)$$

In Table IV values of A and b obtained by utilizing Equations 9 and 10 are compared to those values of A and b obtained from the original GLM analysis.

By using these equations to predict A and b for Equation 2, it would be possible to predict airflow resistance for seed of bulk density from 0.05 to 0.12 g/cm**3 and moisture content from 17.5 to 78.6%.

Regional Division of Airflow

Several researchers (Sheldon, 1961 and Akritidis and Siatras, 1978) have reported three distinct segments on airflow curves, corresponding to laminar, transitional and turbulent flow patterns. These segments have distinctly different slope and intercept values. For example, Akritidis gives the following values for pumpkin seed at 14.5% mc(w.b.):

Region	A	b
1	1.66	0.67
2	2.20	0.55
3	2.8	0.48

At least one of the bluestem curves appears to have different segments. For example, Figure 7 illustrates a plot of the data for seed at BDD = 0.054 along with the predicted curve.

TABLE IV

COMPARISON OF ORIGINAL A AND B VALUES WITH CALCULATED VALUES

BDD	BDW	MC	A	b	A(calc)	b(calc)
0.035	0.050	42.6	-1.51	0.61	-1.52	0.59
0.043	0.050	17.6	-1.75	0.57	-1.76	0.59
0.045	0.080	78.6	-1.78	0.61	-1.80	0.64
0.054	0.096	78.6	-1.79	0.62	-1.80	0.60
0.054	0.080	47.8	-1.79	0.63	-1.82	0.64
0.063	0.090	42.6	-1.90	0.62	-1.91	0.62
0.067	0.120	78.6	-1.65	0.47	-1.68	0.47
0.074	0.110	47.8	-1.86	0.52	-1.88	0.54

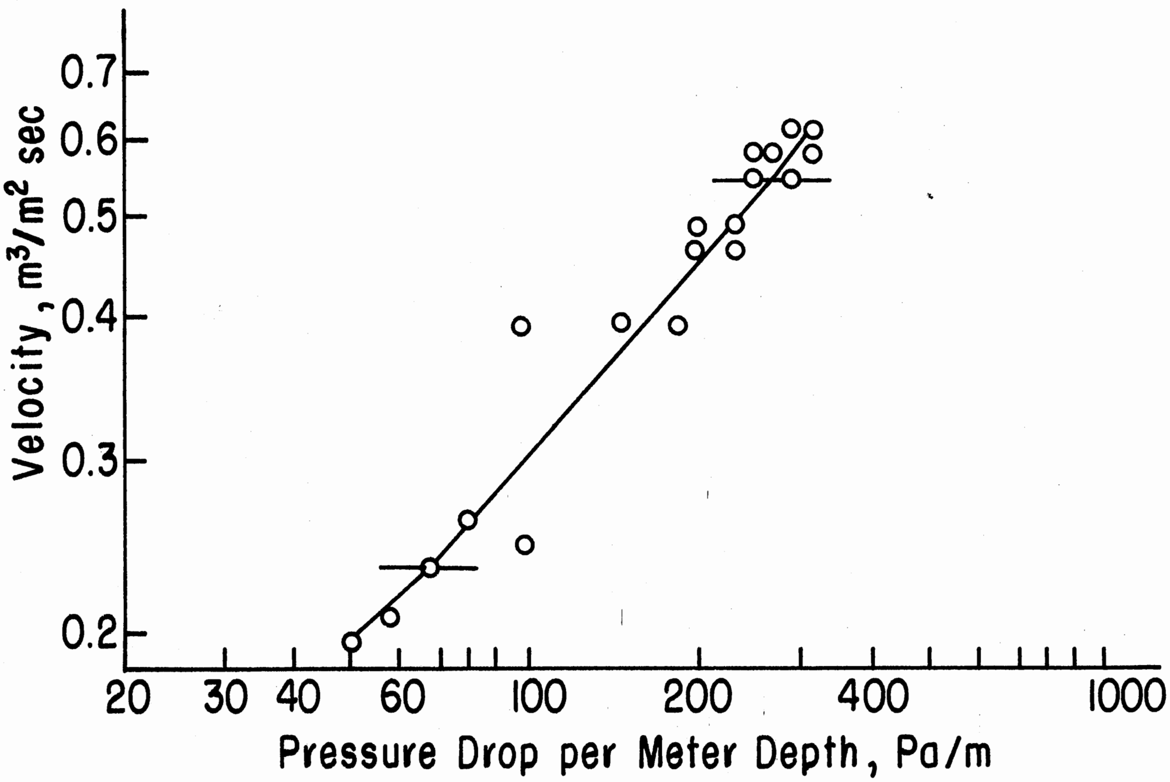


Figure 7. Resistance of Bluestem Grass Seed to Airflow at BDD of 0.054 g/cm**3

This data can be reanalyzed with separate regression analyses performed on the following three ranges of velocity: 1) less than 0.275 m/s 2) between 0.275 and 0.58 m/s and 3) greater than 0.58 m/s. Predicted values for A and b in these analyses are quite different. These resulting values are shown in Table V along with the first prediction. Then, listed in Table VI is a comparison between the percentage error using the first value to calculate velocity and the percentage error when these new values are used for the velocity calculation. On the whole, there is a mean decrease of 1.4% in error using the new values. This does not represent a very large gain in accuracy. Furthermore, there is not enough data available at most of the other bulk densities to make a similar analysis and therefore it can not be done for every curve. Another difficulty involved in making this type of analysis is that the decision as to where to divide the curve is rather arbitrary since there is not a radical change in the slope at any one point. In fact, many of the curves appear to have a single slope. Figure 8 is a plot at BDD of 0.043 and illustrates this point. A continuous slope indicates a uniform flow pattern for the range of velocity encountered.

TABLE V

COMPARISON OF A AND B VALUES WITH FLOW DIVIDED BY REGIONS

BDD	Velocity Range,m/s	R SQUARE	A	b	no. of obs.
0.054	0.18-0.66	0.953	-1.79	0.63	24
0.054	0.18-0.38	0.808	-1.50	0.46	7
0.054	0.39-0.58	0.775	-1.23	0.39	14
0.054	0.59-0.66	0.206	-0.86	0.26	3

TABLE VI

COMPARISON OF CALCULATED VELOCITIES
USING TWO REGRESSION ANALYSES

OBS	PDROP	XVEL	VHAT	DIFF	ERROR2	VOLD	DIFF1	ERROR1
1	49.0	0.18	0.19	-0.01	-4.9	0.19	-0.01	-4.6
2	49.0	0.19	0.19	0.00	0.6	0.19	0.00	0.9
3	59.7	0.20	0.21	-0.01	-3.4	0.21	-0.01	-6.6
4	68.2	0.23	0.22	0.01	4.3	0.23	-0.00	-0.8
5	100.2	0.24	0.26	-0.02	-9.6	0.30	-0.06	-23.1
6	76.7	0.25	0.23	0.02	7.0	0.25	0.00	0.1
7	80.6	0.25	0.24	0.01	4.9	0.26	-0.01	-3.0
8	149.2	0.39	0.42	-0.03	-6.5	0.38	0.01	2.6
9	100.2	0.39	0.36	0.03	8.5	0.30	0.09	24.2
10	183.3	0.40	0.45	-0.05	-12.3	0.43	-0.03	-8.1
11	192.6	0.45	0.46	-0.01	-1.7	0.45	0.00	0.9
12	234.5	0.45	0.49	-0.04	-9.7	0.50	-0.05	-12.2
13	234.5	0.49	0.49	-0.00	-0.7	0.50	-0.01	-3.0
14	196.1	0.49	0.46	0.03	5.9	0.45	0.04	7.9
15	253.9	0.53	0.51	0.02	4.0	0.53	-0.00	-0.2
16	298.5	0.53	0.54	-0.01	-2.1	0.59	-0.06	-10.9
17	292.1	0.54	0.54	0.00	0.6	0.58	-0.04	-7.4
18	326.2	0.56	0.56	0.00	0.0	0.62	-0.06	-11.0
19	280.2	0.57	0.53	0.04	7.3	0.56	0.01	0.9
20	319.8	0.58	0.56	0.02	4.2	0.61	-0.03	-5.8
21	326.2	0.62	0.64	-0.02	-3.2	0.62	-0.00	-0.2
22	292.1	0.62	0.62	-0.00	-0.2	0.58	0.04	6.5
23	324.0	0.66	0.64	0.02	3.3	0.62	0.04	6.2

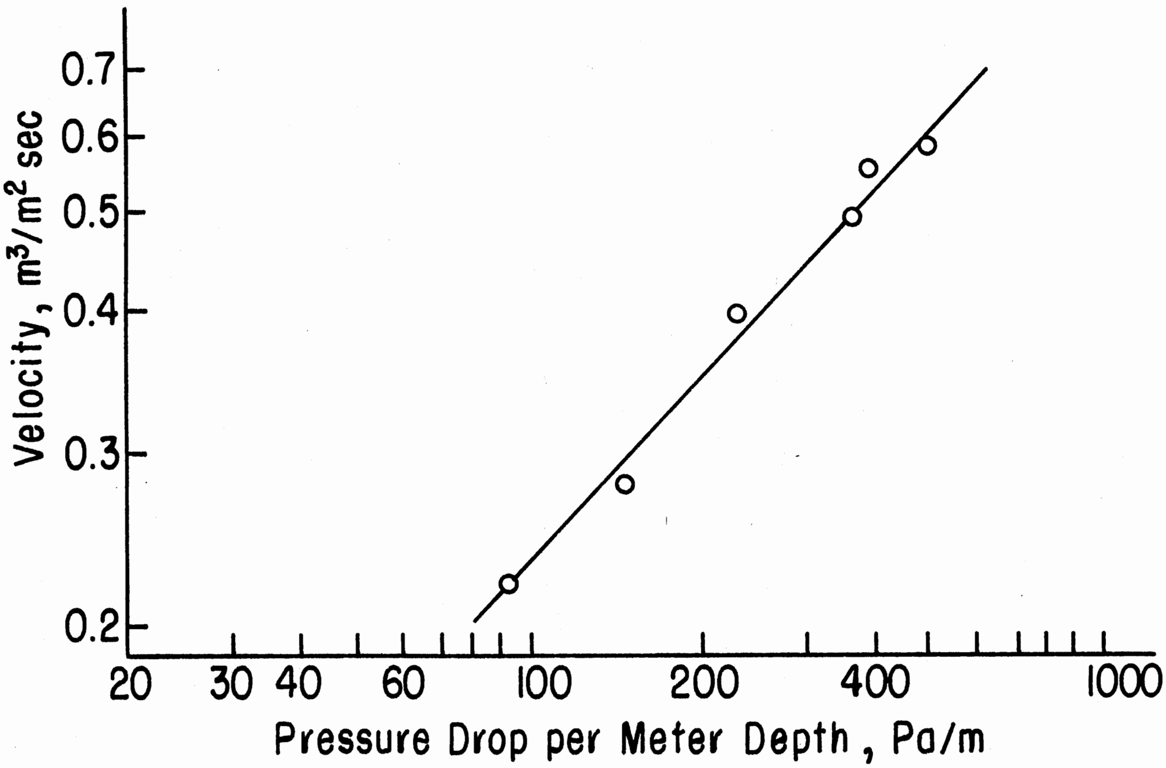


Figure 8. Resistance to Airflow for M.C. of 78.6%
at BDD of 0.045 g/cm**3

Equilibrium Moisture Content

Desorption Curves

When freshly harvested seed was placed in an environment at constant relative humidity at 20C, the desorption curve which resulted was similar to that reported by Haynes (1956) for corn at 16C. Since seed tested included four different harvests representing purities ranging from 10.6 to approximately 30%, there was some variation in the range of equilibrium moisture content at each relative humidity but the general shape of the curves was similar. A comparison of the desorption curve of bluestem at a purity of 17.9% to that of Haynes corn curve is made in Figure 9 where mean experimental moisture content is plotted against relative humidity. Mean equilibrium moisture contents are listed for each purity in Table VII . The exact purity of the October 11 harvest is not known since the seed molded during drying. However, purities from other seed harvested at the same time and location indicate. a reasonable estimate of the purities to be 30% (Whitney, 1978).

Adsorption Curves

Since dried seed can be stored without mold damage, more extensive testing was possible using the dry seed. The general shape of the adsorption curve was comparable to

TABLE VII

MEAN EMC AFTER DESORPTION

Mean EMC at Four Relative Humidities for Four Purities

PURITY,%	23.3%RH	43.9%RH	75.5%RH	93.5%RH
10.6	7.8	10.5	19.2	36.6
17.9	7.3	10.6	18.4	40.6
21.3	6.3	8.6	17.8	39.1
?30	9.1	11.5	19.5	36.4
Mean of All Purities	7.6	10.3	18.7	38.2

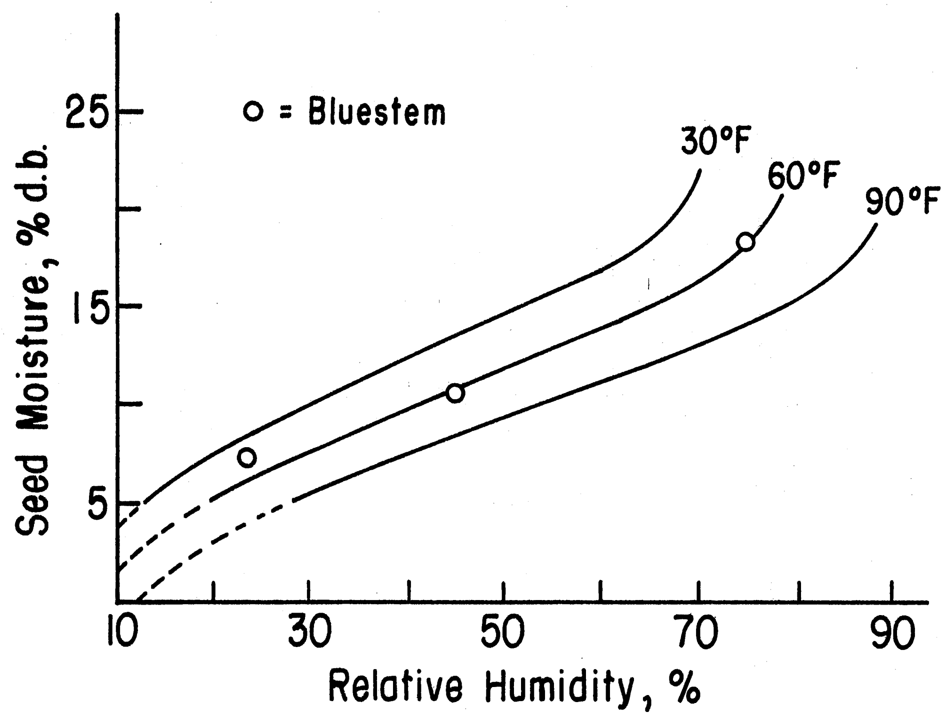


Figure 9. Desorption EMC of Bluestem Compared with Haynes Corn Curves

Lamour's (1944) flax seed adsorption curve. Figure 10 represents a comparison of the average EMC for five purities ranging from 10.6 to 63.4% to the flaxseed data. Since the dried seed had been held in storage at a humidity in the 40-50% range, this seed when placed in a RH of 23.2% would be desorbing rather than adsorbing so that set of values was excluded from the adsorption data. The flaxseed study had been carried out at 25C compared to 20C for the bluestem. Again, there was variation of equilibrium moisture content with purity; Table VIII contains a tabulation of mean EMC at each purity.

Since data were available for both the adsorption and desorption study for only two of the purities, comparison of the adsorption and desorption isotherms of bluestem was limited to the average EMC of these purities. When such a comparison was made, the difference between the two is greater at the higher relative humidities. This is illustrated in Figure 11 where a regression curve of each is plotted.

Hysteresis Effect

There were no examples in the literature of the hysteresis effect on grass seeds; however, Chung and Pfost (1967) did a rather comprehensive study of the hysteresis effect on corn. They found the difference between the two isotherms to be fairly constant with the desorption line

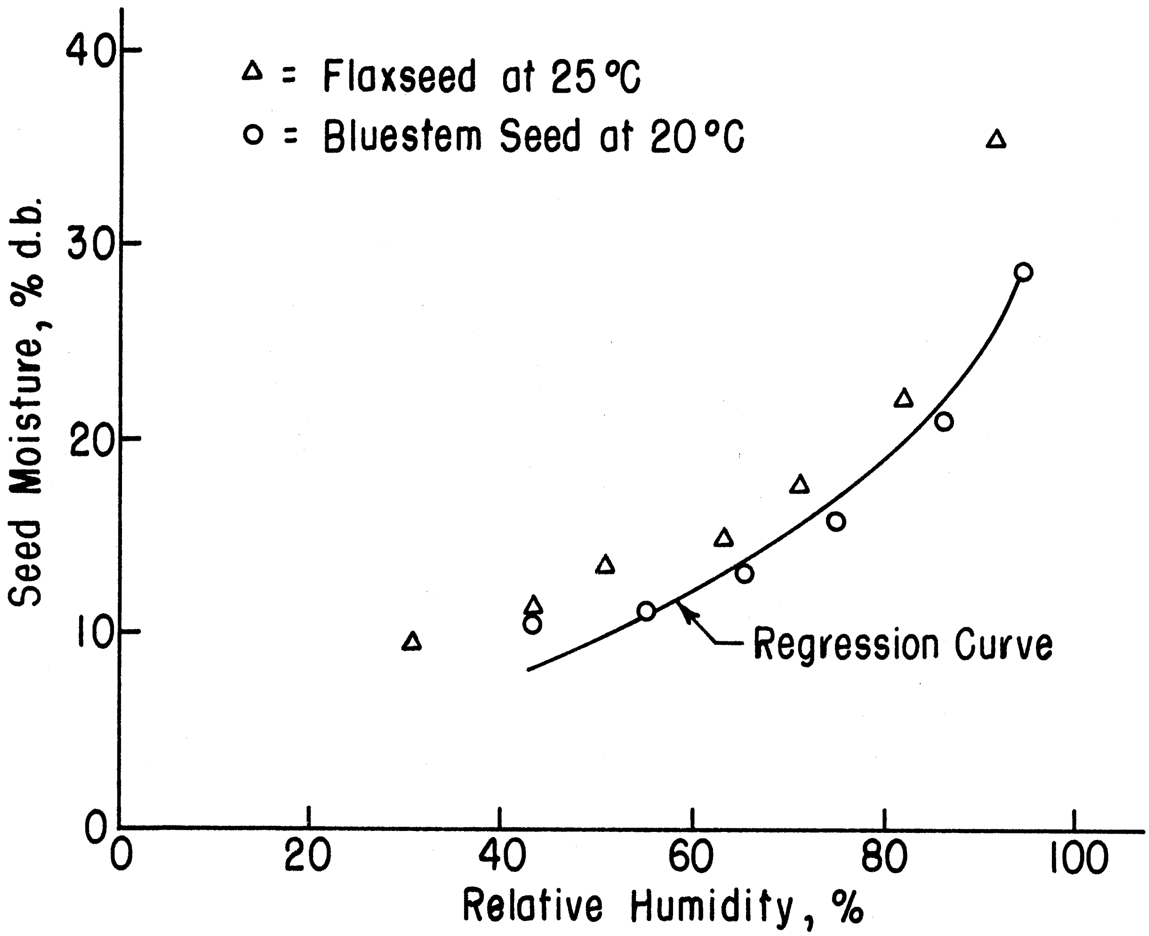


Figure 10. A Comparison of the Desorption Curve of Bluestem with That of Flaxseed

TABLE VIII

MEAN EMC AFTER ADSORPTION FOR SIX RELATIVE HUMIDITIES

% Purity	Relative Humidity 43.9	55.2	65.3	75.5	86.6	93.5
10.6	-	-	-	-	22.97	30.69
17.9	10.29	10.87	12.89	16.84	20.53	29.14
21.3	10.28	11.04	13.51	16.09	22.48	29.08
34.5	-	10.31	12.17	14.62	19.13	27.20
63.4	-	10.86	12.42	14.63	18.49	28.79
Mean of all Purities	10.29	10.77	12.75	15.94	20.72	29.03

Note: Missing values are the result of data omitted when initial MC of seed was higher than EMC since this indicated a desorptive instead of an adsorptive state.

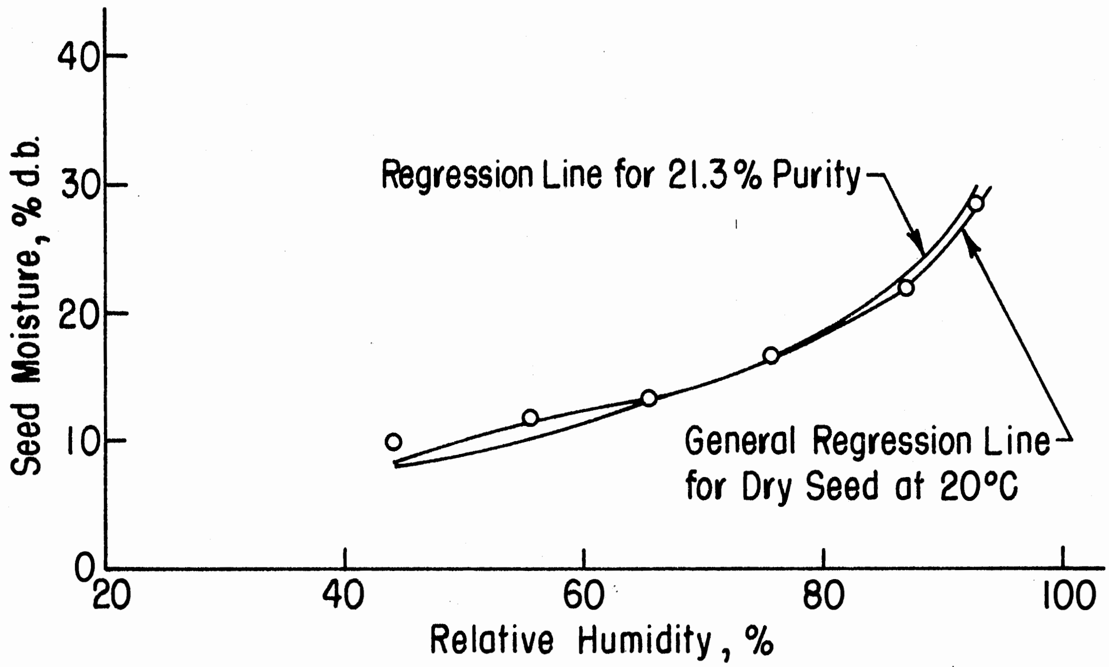


Figure 11. Comparison of the Adsorption and Desorption Isotherms of Bluestem at 20C

falling 1.5-2.0 percentage points higher than that of the adsorption line. The bluestem adsorption line is almost 10% lower at the highest relative humidity but gradually comes closer to the desorption line until they merge at about 44% relative humidity which was probably the starting point for the dried seed since it had been stored at approximately that relative humidity.

Effect of Purity on EMC

Complete data for a range of purities from 17.9 to 63.4% at relative humidities from 55.2 to 93.5% was available from the studies with the dried seed. Mean moisture contents for each purity are listed by relative humidity in Table VIII . From these figures it appears that higher purities have generally lower values for EMC at most relative humidities. The deviation due to purity became greater with increased humidity. An Analysis of Variance was conducted on relative humidity and purity. Results are listed in Table IX .

Effect of Temperature on EMC

The Aminco Aire unit was employed in an effort to achieve a greater range of relative humidities while observing the effect of temperature on EMC. While the salt solutions had been held at a temperature of 20C, the environmental chamber was maintained at 32C. However, efforts to reach a relative humidity in the chamber below 20

TABLE IX

ANALYSIS OF VARIANCE ON THE EFFECT OF PURITY ON EMC

SOURCE	d.f.	s.s.	m.s.	F	OSL
Total	69	1668.20	-	-	-
Treatment	19	1665.29	87.65	602.90	0.0001
Purity	3	28.21	-	64.68	0.0001
RH	4	1623.10	-	2791.36	0.0001
Purity*RH	12	14.02	-	8.04	0.0001
Error	20	2.91	0.14	-	-

or above 90% were unsatisfactory so the range was similar to that achieved with the salt solutions. Furthermore, since the unit was in fact quite difficult to maintain at the extremes of that range, often requiring more than two weeks to reach equilibrium, fewer tests were conducted at the temperature. However, sufficient data were collected to demonstrate the lowering of the isotherm at the higher temperature. Figure 12 depicts the desorption isotherms for seed at a purity of 10.6% at temperatures of 20 and 32C.

Application of Chung Pfost Equation

In an attempt to model the relationship between the EMC of bluestem grass seed and the relative humidity of the surrounding air, the Chung-Pfost model (1961) was chosen since this equation has been cited as an appropriate model for seeds in the 20 to 90% relative humidity range (Brooker et al., 1977). The equation is as follows:

$$\mathrm{Ln}(RH) = (-A/RT)\exp(-BM_e) \qquad (13)$$

where:

- RH = the relative humidity expressed as a decimal
- A and B = constants related to product and temperature
- R = the ideal gas constant
- T = the absolute Temperature
- M_e = equilibrium moisture content, % dry basis.

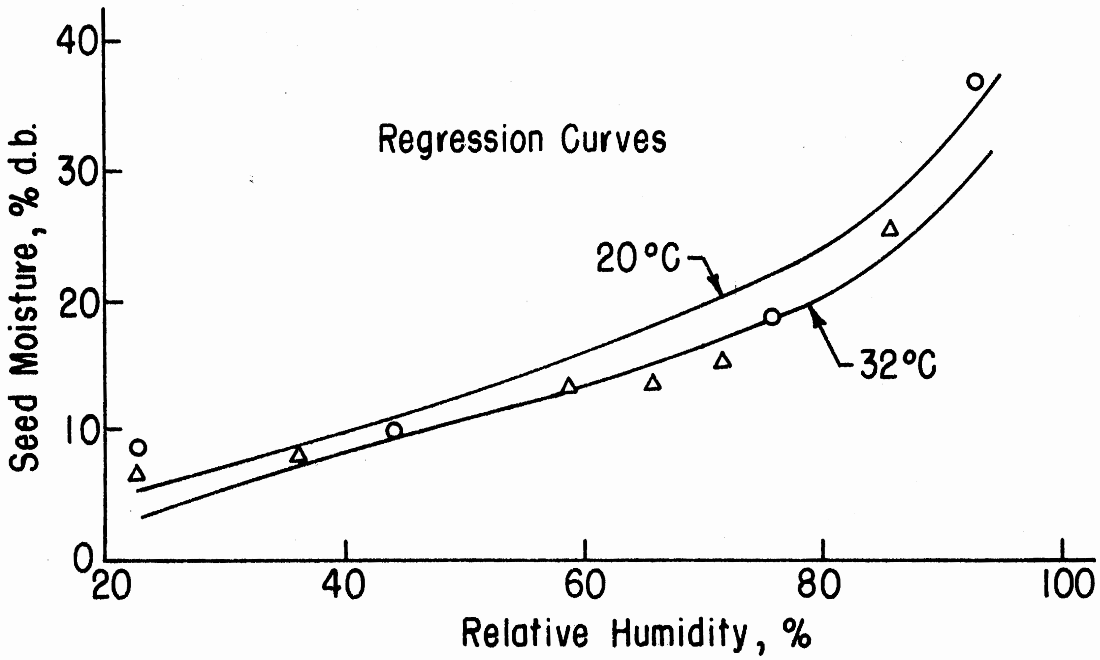


Figure 12. Comparison of the 20 and 32C Desorption Isotherms for Purity 10.6%

Inasmuch as the predicted curves are isotherms, T can be considered as a constant and since R is also a constant, the entire expression A/RT can be written as one constant which will be hereafter denoted as K. The equation can thus be rewritten as:

$$Ln(RH) = -K(exp(BM_e)) \qquad (14)$$

A regression analysis using the GLM Procedure (Barr et al.,1976) was performed on the data separated by purity, temperature and adsorptive or desorptive state. The analysis was applied to the model in the form:

$$ln[ln(-RH)] = C + BM_e \qquad (15)$$

where C = ln(K). Resulting R Square values were all above 0.9. The analysis was then repeated on the data disregarding purities. That is, the following groups were analyzed: (1) the adsorption data at 20C (2) all the undried seed at 20C (3) the adsorption data at 32C and (4) all the undried seed at 32C. Again, R Square values were above 0.9 but somewhat lower than those from the preceding analyses. A final analysis was done on all data regardless of temperature, sorptive state or purity. This R Square value was still lower at 0.86. These R Square Values are listed in Table X for each regression analysis performed.

In calculating an equilibrium at a given RH for each of these temperatures during either sorptive state, there are therefore three possible equations, one including and one

TABLE X

SUMMARY OF VALUES OBTAINED FROM REGRESSION ANALYSES OF EMC-RH DATA

Purity %	Temp C	State A or D'	Initial M.C.,%	B	C	R Square
all	20	A	dry	-0.121	0.761	0.954
10.6	20	A	20.9	-0.097	0.300	0.990
17.9	20	A	8.7& 9.1	-0.127	0.933	0.968
22.3	20	A	9.1& 9.8	-0.124	0.866	0.978
34.5	20	A	10.3	-0.128	0.683	0.980
63.4	20	A	10.5	-0.118	0.556	0.941
all	20	D	wet	-0.092	0.770	0.941
10.6	20	D	47.8	-0.103	0.959	0.976
17.9	20	D	42.6	-0.088	0.749	0.953
21.3	20	D	46.8	-0.086	0.599	0.930
30'"	20	D	76.8	-0.108	1.120	0.970
10.6	32	D	47.8	-0.115	0.927	0.916
10.6	32	A	16.8	-0.157	1.480	0.986
17.9	32	A	9.0	-0.193	1.460	0.985
"	32	A	"	-0.153	1.220	0.921
----ALL SEED------				-0.100	0.609	0.868

' A = Adsorption and D = Desorption

" Data included a combination of purities 10.6 and 17.9% at moistures of 16.8 and 9.0%

'" Exact purity unknown but estimated to be about 30%

excluding purity at a given temperature and state and one disregarding purity, state and temperature. A comparison of the calculated EMC value using the single equation, the equation for state and temperature without regard to purity, and the family of purity equations was made and these are listed in Appendix C. As a rule, the calculated moisture using the generalized equation for a given state and temperature is not greatly different than that calculated from the specific purity equations. Since purity information is not readily obtained and can vary greatly from harvest to harvest, the usefullness of constants derived for a specific purity is questionable. They were included here as a means of comparison since earlier statistical analysis had shown that purity did effect EMC. A comparison at a purity of 21.3% which is typical of comparisons at any of the purities studied is made in Figure 13 .

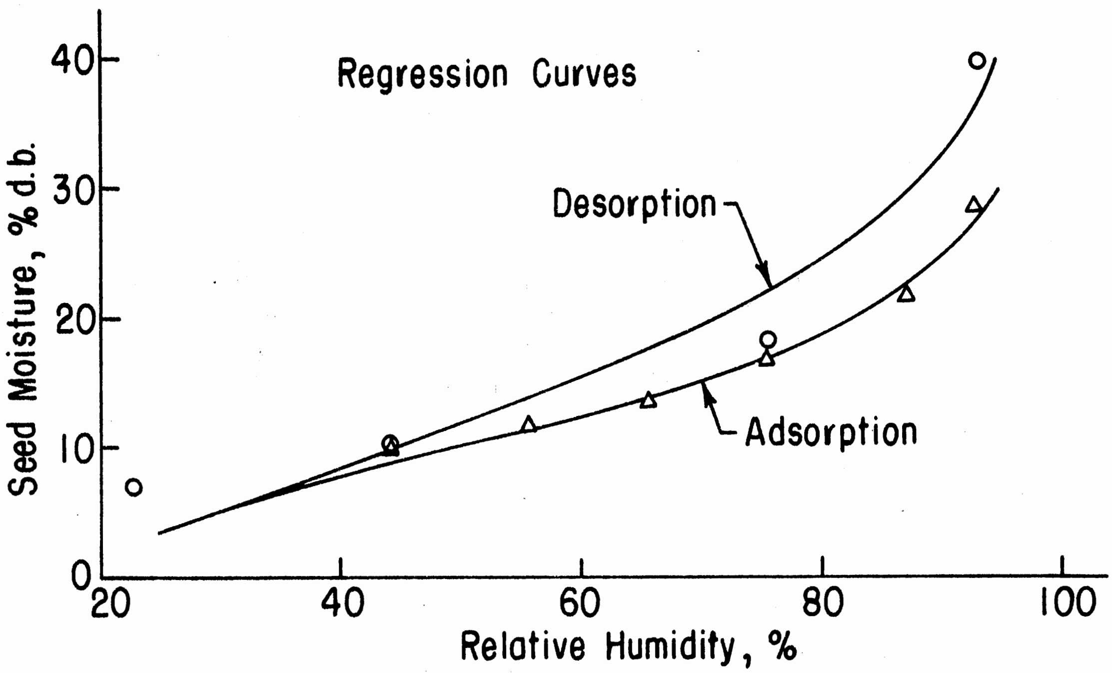


Figure 13. A Comparison of the Mean Values with Calculated Moistures

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The resistance to airflow of bluestem grass seed was determined experimentally at varied bulk densities of both undried and dried seed. The effects of bulk density, moisture content and purity on airflow were studied. By the use of regression analysis , constants were derived for the equation developed by Shedd relating airflow to static pressure drop. These derived constants were then related to moisture content and bulk density.

Adsorption-desorption equilibrium moisture content curves at 20 and 32C were developed experimentally for the relative humidity range of 20-93%. Environmental control was achieved through both static and dynamic methods. Experimental results were then used to test the applicability of the Chung-Pfost equation to the relationship of relative humidity and equilibrium moisture content of bluestem.

Conclusions

The following conclusions were reached in the study:

1) Bulk density is the most important parameter affecting the airflow through a bed of bluestem grass seed. At constant moisture content and seed purity, air flow varies inversely with bulk density.

2) The purity of the seed per se does not appear to directly affect aiflow. Purity does, however, influence bulk density which was found to affect airflow. Seed with higher purities settles to a state of high bulk density.

3) Moisture content contributes to airflow resistance both directly and indirectly. Moisture content adds to the bulk density when calculated on a total weight basis but this effect can be ignored by calculating bulk density on the basis of dry matter present. At the same dry matter bulk density, dry seed offers more resistance to airflow than undried seed.

4) The Chung-Pfost equation can effectively be used to define the bluestem EMC curve. A single generalized equation was developed with an R Square of 0.87.

Suggestions for Further Study

1) Further testing with seed at a wider range of bulk densities is necessary to test the reliability of the equation developed for predicting constants for the pressure drop-airflow relationship.

2) Trials to determine the effect of purity on airflow were limited to low airflows by the available equipment. Determination of the effect of purity on higher airflows is needed to make more general predictions.

3) Some inconsistency of the EMC curve at low relative humidities suggests the need for more work in that area.

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APPENDICES

APPENDIX A

A COMPARISON OF THE EXPERIMENTAL AND CALCULATED AIR VELOCITIES

LIST OF VARIABLES IN APPENDIX A

BDD,	dry matter bulk density, g dry matter/cm**3
BDW,	wet matter bulk density, g total matter/cm**3
DEPTH,	bed depth, m
DIFF,	difference between experimental and calculated velocities, m/s
ERROR,	percentage error in calcuated velocity, %
HARVEST,	date of harvest
PDROP,	pressure drop per m of bed depth, Pa/m
VHAT,	velocity calculated using constants derived from regression analysis, m/s
XVEL,	experimental velocity, m/sec

TABLE XI

A COMPARISON OF THE EXPERIMENTAL AND CALCULATED AIR VELOCITIES[1]

OBS	BDD	BDW	DEPTH	HARVEST	PDROP	XVEL	VHAT	DIFF	ERROR
1	.035	.050	.56	JULY6	227.6	.87	.84	0.03	3.7
2	.035	.050	.56	JULY6	210.1	.82	.80	0.02	2.7
3	.035	.050	.56	JULY6	199.6	.76	.77	-.01	-1.8
4	.035	.050	.56	JULY6	161.1	.66	.68	-.02	-2.9
5	.035	.050	.56	JULY6	15.8	.18	.17	0.01	8.1
6	.035	.050	.56	JULY6	43.8	.31	.31	0.00	0.8
7	.035	.050	.56	JULY6	70.0	.41	.41	0.00	0.2
8	.035	.050	.56	JULY6	29.8	.23	.24	-.01	-5.8
9	.043	.050	.46	OCT 21	166.3	.33	.33	-.00	-1.3
10	.043	.050	.56	OCT 21	162.9	.31	.33	-.02	-6.5
11	.043	.050	.56	OCT 21	236.4	.39	.41	-.02	-4.9
12	.043	.050	.56	OCT 21	320.5	.44	.49	-.05	-10.8
13	.043	.050	.61	OCT 21	151.1	.32	.32	0.00	1.2
14	.043	.050	.61	OCT 21	215.4	.42	.39	0.03	7.7
15	.043	.050	.61	OCT 21	65.9	.22	.20	0.02	10.8
16	.043	.050	.56	OCT 21	87.6	.20	.23	-.03	-15.6
17	.043	.050	.46	OCT 21	81.0	.22	.22	-.00	-0.5
18	.043	.050	.46	OCT 21	341.1	.49	.51	-.02	-3.1
19	.043	.050	.61	OCT 21	265.3	.49	.44	0.05	10.8
20	.045	.080	.30	OCT11	160.8	.39	.37	0.02	5.6
21	.045	.080	.30	OCT11	379.4	.62	.62	-.00	-0.2
22	.045	.080	.30	OCT11	456.6	.66	.70	-.04	-5.3
23	.045	.080	.30	OCT11	292.6	.57	.53	0.04	7.0
24	.045	.080	.30	OCT11	418.0	.65	.66	-.01	-1.3
25	.045	.080	.30	OCT11	99.7	.26	.28	-.02	-5.9
26	.054	.096	.46	OCT11	326.2	.62	.61	0.01	1.1
27	.054	.096	.46	OCT11	234.5	.49	.50	-.01	-1.8
28	.054	.096	.46	OCT11	149.2	.39	.38	0.01	3.7
29	.054	.096	.46	OCT11	292.1	.54	.57	-.03	-6.0
30	.054	.096	.46	OCT11	319.8	.58	.61	-.03	-4.4
31	.054	.096	.46	OCT11	76.7	.25	.25	0.00	1.0
32	.054	.096	.46	OCT11	59.7	.20	.21	-.01	-5.8
33	.054	.080	.46	OCT21	196.1	.49	.45	0.04	9.0
34	.054	.080	.56	OCT21	49.0	.18	.19	-.01	-3.9
35	.054	.080	.46	OCT21	49.0	.19	.19	0.00	1.6
36	.054	.080	.46	OCT21	100.2	.39	.29	0.10	25.0
37	.054	.080	.46	OCT21	183.3	.40	.43	-.03	-6.8
38	.054	.080	.46	OCT21	68.2	.23	.23	0.00	0.0
39	.054	.080	.46	OCT21	100.2	.24	.29	-.05	-21.9
40	.054	.080	.56	OCT21	80.6	.25	.26	-.01	-2.1

[1]Part A--From constants derived from the regression analysis of BDD data

TABLE XI

A COMPARISON OF THE EXPERIMENTAL AND CALCULATED AIR VELOCITIES[1]

OBS	BDD	BDW	DEPTH	HARVEST	PDROP	XVEL	VHAT	DIFF	ERROR
41	.054	.080	.46	OCT21	292.1	.62	.57	0.05	7.7
42	.054	.080	.56	OCT21	280.2	.57	.56	0.01	2.2
43	.054	.080	.56	OCT21	253.9	.53	.52	0.01	1.1
44	.054	.080	.46	OCT21	255.8	.58	.53	0.05	9.2
45	.054	.080	.46	OCT21	298.5	.53	.58	-.05	-9.5
46	.054	.080	.46	OCT21	326.2	.56	.61	-.05	-9.5
47	.054	.080	.46	OCT21	234.5	.45	.50	-.05	-10.8
48	.054	.080	.56	OCT21	192.6	.45	.44	0.01	2.0
49	.054	.080	.46	OCT21	324.0	.66	.61	0.05	7.5
50	.063	.090	.30	JULY6	90.0	.21	.21	0.00	2.0
51	.063	.090	.30	JULY6	395.5	.54	.52	0.02	4.3
52	.063	.090	.30	JULY6	360.1	.49	.49	0.00	0.5
53	.063	.090	.30	JULY6	514.4	.58	.61	-.03	-5.0
54	.063	.090	.30	JULY6	228.3	.39	.37	0.02	5.8
55	.063	.090	.30	JULY6	147.9	.26	.28	-.02	-7.8
56	.043	.050	.61	OCT 21	250.8	.47	.42	0.05	9.9
57	.067	.120	.51	OCT11	322.4	.37	.34	0.03	8.6
58	.067	.120	.36	OCT11	207.0	.26	.27	-.01	-5.6
59	.067	.120	.36	OCT11	81.7	.21	.18	0.03	15.6
60	.067	.120	.20	OCT11	401.0	.34	.37	-.03	-10.1
61	.067	.120	.36	OCT11	307.8	.34	.33	0.01	2.7
62	.067	.120	.51	OCT11	175.7	.25	.25	-.00	-1.6
63	.067	.120	.51	OCT11	102.3	.19	.20	-.01	-3.7
64	.067	.120	.51	OCT11	347.5	.39	.35	0.04	10.2
65	.067	.120	.36	OCT11	422.2	.40	.38	0.02	4.1
66	.067	.120	.20	OCT11	830.9	.54	.53	0.01	2.3
67	.067	.120	.20	OCT11	748.8	.51	.50	0.01	1.5
68	.067	.120	.20	OCT11	570.0	.43	.44	-.01	-2.8
69	.067	.120	.51	OCT11	231.6	.29	.29	0.00	0.2
70	.067	.120	.36	OCT11	457.6	.42	.40	0.02	5.1
71	.067	.120	.20	OCT11	207.7	.21	.27	-.06	-30.9
72	.067	.120	.51	OCT11	312.7	.35	.33	0.02	4.8
73	.074	.110	.40	OCT 21	416.8	.29	.32	-.03	-9.7
74	.074	.110	.36	OCT 21	365.0	.30	.30	0.00	1.0
75	.074	.110	.40	OCT 21	343.2	.26	.29	-.03	-10.7
76	.074	.110	.36	OCT 21	261.5	.27	.25	0.02	7.5
77	.074	.110	.40	OCT 21	281.9	.24	.26	-.02	-8.2
78	.074	.110	.36	OCT 21	133.5	.18	.18	0.00	2.1
79	.074	.110	.36	OCT 21	463.1	.39	.34	0.05	13.8

[1]Part A--From constants derived from the regression analysis of BDD data

TABLE XI

A COMPARISON OF THE EXPERIMENTAL AND CALCULATED AIR VELOCITIES[1]

OBS	BDD	BDW	DEPTH	HARVEST	PDROP	XVEL	VHAT	DIFF	ERROR
1	.035	.050	.56	JULY6	227.6	.87	.48	0.39	44.7
2	.035	.050	.56	JULY6	15.8	.18	.17	0.01	6.3
3	.035	.050	.56	JULY6	210.1	.82	.47	0.35	43.1
4	.035	.050	.56	JULY6	199.6	.76	.46	0.30	39.8
5	.035	.050	.56	JULY6	161.1	.66	.42	0.24	36.3
6	.035	.050	.56	JULY6	43.8	.31	.25	0.06	18.7
7	.035	.050	.56	JULY6	70.0	.41	.30	0.11	26.1
8	.035	.050	.56	JULY6	29.8	.23	.22	0.01	5.8
9	.043	.050	.61	OCT 21	250.8	.47	.50	-.03	-6.4
10	.043	.050	.56	OCT 21	162.9	.31	.42	-.11	-36.1
11	.043	.050	.56	OCT 21	236.4	.39	.49	-.10	-25.3
12	.043	.050	.56	OCT 21	320.5	.44	.55	-.11	-25.1
13	.043	.050	.61	OCT 21	151.1	.32	.41	-.09	-28.1
14	.043	.050	.46	OCT 21	166.3	.33	.43	-.10	-28.9
15	.043	.050	.61	OCT 21	215.4	.42	.47	-.05	-12.1
16	.043	.050	.61	OCT 21	65.9	.22	.30	-.08	-34.5
17	.043	.050	.56	OCT 21	87.6	.20	.33	-.13	-65.4
18	.043	.050	.46	OCT 21	81.0	.22	.32	-.10	-45.8
19	.043	.050	.46	OCT 21	341.1	.49	.56	-.07	-15.1
20	.043	.050	.61	OCT 21	265.3	.49	.51	-.02	-4.3
21	.045	.080	.30	OCT11	160.8	.39	.39	0.00	0.2
22	.045	.080	.30	OCT11	379.4	.62	.66	-.04	-5.9
23	.045	.080	.30	OCT11	456.6	.66	.73	-.07	-11.3
24	.045	.080	.30	OCT11	292.6	.57	.56	0.01	1.7
25	.045	.080	.30	OCT11	418.0	.65	.70	-.05	-7.1
26	.045	.080	.30	OCT11	99.7	.26	.29	-.03	-12.0
27	.054	.080	.46	OCT21	196.1	.49	.44	0.05	10.3
28	.054	.080	.46	OCT21	49.0	.19	.19	0.00	0.4
29	.054	.080	.46	OCT21	100.2	.39	.29	0.10	25.1
30	.054	.080	.46	OCT21	183.3	.40	.42	-.02	-5.4
31	.054	.080	.46	OCT21	68.2	.23	.23	-.00	-0.5
32	.054	.080	.46	OCT21	100.2	.24	.29	-.05	-21.7
33	.054	.080	.56	OCT21	80.6	.25	.26	-.01	-2.3
34	.054	.080	.46	OCT21	292.1	.62	.56	0.06	9.7
35	.054	.080	.56	OCT21	280.2	.57	.55	0.02	4.2
36	.054	.080	.56	OCT21	253.9	.53	.51	0.02	3.0
37	.054	.080	.46	OCT21	255.8	.58	.52	0.06	11.0
38	.054	.080	.46	OCT21	255.8	.58	.52	0.06	11.0
39	.054	.080	.46	OCT21	298.5	.53	.57	-.04	-7.0
40	.054	.080	.46	OCT21	326.2	.56	.60	-.04	-6.9

[1]Part B--From constants derived from the regression analysis of BDW data

TABLE XI

A COMPARISON OF THE EXPERIMENTAL AND CALCULATED AIR VELOCITIES[1]

OBS	BDD	BDW	DEPTH	HARVEST	PDROP	XVEL	VHAT	DIFF	ERROR
41	.054	.080	.46	OCT21	234.5	.45	.49	-.04	-8.9
42	.054	.080	.56	OCT21	192.6	.45	.43	0.02	3.4
43	.054	.080	.46	OCT21	324.0	.66	.60	0.06	9.7
44	.054	.080	.56	OCT21	49.0	.18	.19	-.01	-5.1
45	.063	.090	.30	JULY6	90.0	.21	.21	0.00	2.0
46	.063	.090	.30	JULY6	395.5	.54	.52	0.02	4.3
47	.063	.090	.30	JULY6	360.1	.49	.49	0.00	0.5
48	.063	.090	.30	JULY6	514.4	.58	.61	-.03	-5.0
49	.063	.090	.30	JULY6	228.3	.39	.37	0.02	5.8
50	.063	.090	.30	JULY6	147.9	.26	.28	-.02	-7.8
51	.054	.096	.46	OCT11	326.2	.62	.60	0.02	2.9
52	.054	.096	.46	OCT11	234.5	.49	.49	0.00	0.1
53	.054	.096	.46	OCT11	149.2	.39	.37	0.02	5.3
54	.054	.096	.46	OCT11	292.1	.54	.56	-.02	-4.0
55	.054	.096	.46	OCT11	319.8	.58	.59	-.01	-2.5
56	.054	.096	.46	OCT11	76.7	.25	.24	0.01	2.4
57	.054	.096	.46	OCT11	59.7	.20	.21	-.01	-4.3
58	.074	.110	.40	OCT 21	416.8	.29	.32	-.03	-9.7
59	.074	.110	.36	OCT 21	365.0	.30	.30	0.00	1.0
60	.074	.110	.40	OCT 21	343.2	.26	.29	-.03	-10.7
61	.074	.110	.36	OCT 21	261.5	.27	.25	0.02	7.5
62	.074	.110	.40	OCT 21	281.9	.24	.26	-.02	-8.2
63	.074	.110	.36	OCT 21	463.1	.39	.34	0.05	13.8
64	.074	.110	.36	OCT 21	133.5	.18	.18	0.00	2.1
65	.067	.120	.51	OCT11	312.7	.35	.33	0.02	4.8
66	.067	.120	.36	OCT11	207.0	.26	.27	-.01	-5.6
67	.067	.120	.36	OCT11	81.7	.21	.18	0.03	15.6
68	.067	.120	.20	OCT11	401.0	.34	.37	-.03	-10.1
69	.067	.120	.36	OCT11	307.8	.34	.33	0.01	2.7
70	.067	.120	.51	OCT11	175.7	.25	.25	-.00	-1.6
71	.067	.120	.51	OCT11	102.3	.19	.20	-.01	-3.7
72	.067	.120	.51	OCT11	347.5	.39	.35	0.04	10.2
73	.067	.120	.36	OCT11	422.2	.40	.38	0.02	4.1
74	.067	.120	.20	OCT11	830.9	.54	.53	0.01	2.3
75	.067	.120	.20	OCT11	748.8	.51	.50	0.01	1.5
76	.067	.120	.20	OCT11	570.0	.43	.44	-.01	-2.8
77	.067	.120	.51	OCT11	322.4	.37	.34	0.03	8.6
78	.067	.120	.36	OCT11	457.6	.42	.40	0.02	5.1
79	.067	.120	.20	OCT11	207.7	.21	.27	-.06	-30.9
80	.067	.120	.51	OCT11	231.6	.29	.29	0.00	0.2

[1]Part B--From constants derived from the regression analysis of BDW data

APPENDIX B

RESULTS OF R SQUARE ANALYSIS FOR CHARACTERIZATION OF A AND B CONSTANTS

LIST OF VARIABLES IN APPENDIX B

BDD,	bulk density, dry basis
BDW,	bulk density, wet basis
D2,	BDD**2
MC,	moisture content
PRD,	MC*BDD
PR,	MC*BDW
W2,	BDW**2

TABLE XII

RESULTS OF R SQUARE ANALYSIS WITH BDD AS BULK DENSITY VARIABLE

A = F(MC,M2,PRD,BDD,D2)		b = F(MC,M2,PRD,BDD,D2)	
R SQUARE	VARIABLES IN MODEL	R SQUARE	VARIABLES IN MODEL
0.002	MC	0.026	MC
0.004	M2	0.036	M2
0.022	PRD	0.219	PRD
0.273	D2	0.316	BDD
0.329	BDD	0.365	D2
0.011	MC M2	0.056	MC M2
0.156	M2 PRD	0.317	MC BDD
0.166	MC PRD	0.325	BDD M2
0.293	M2 D2	0.366	BDD PRD
0.299	MC D2	0.368	MC D2
0.323	D2 PRD	0.380	M2 D2
0.356	BDD M2	0.380	D2 PRD
0.364	MC BDD	0.385	M2 PRD
0.411	BDD PRD	0.501	BDD D2
0.530	BDD D2	0.561	MC PRD
0.167	MC M2 PRD	0.380	M2 D2 PRD
0.309	MC D2 M2	0.400	BDD M2 PRD
0.375	MC BDD M2	0.452	MC BDD M2
0.431	MC D2 PRD	0.527	MC BDD D2
0.587	M2 D2 PRD	0.530	MC M2 D2
0.641	MC BDD M2	0.565	BDD M2 D2
0.644	BDD M2 D2	0.573	BDD D2 PRD
0.675	MC BDD PRD	0.585	MC D2 PRD
0.710	BDD M2 PRD	0.599	MC M2 PRD
0.850	BDD M2 PRD	0.693	MC BDD PRD
0.644	MC BDD M2 D2	0.608	MC M2 D2 PRD
0.892	MC BDD D2 PRD	0.695	MC BDD M2 PRD
0.907	MC BDD D2 PRD	0.812	MC BDD M2 D2
0.936	BDD M2 D2 PRD	0.860	MC BDD D2 PRD
0.994	MC BDD M2 D2 PRD	0.920	MC BDD M2 D2 PRD

TABLE XIII

RESULTS OF R SQUARE ANALYSIS WITH BDW AS BULK DENSITY VARIABLE

A = F(MC,M2,BDW,W2,PR)		b = F(MC,M2,BDW,W2,PR)	
R SQUARE	VARIABLES IN MODEL	R SQUARE	VARIABLES IN MODEL
0.002	MC	0.026	MC
0.003	M2	0.036	M2
0.005	PR	0.205	PR
0.087	W2	0.324	BDW
0.147	BDW	0.445	W2
0.011	MC M2	0.056	MC M2
0.087	MC PR	0.328	BDW PR
0.101	M2 PR	0.354	BDW M2
0.162	M2 W2	0.390	MC BDW
0.165	MC W2	0.490	W2 PR
0.199	W2 PR	0.492	M2 PR
0.270	BDW M2	0.493	M2 W2
0.285	MC BDW	0.535	MC W2
0.388	BDW PR	0.632	MC PR
0.540	BDW W2	0.911	BDW W2
0.101	MC M2 PR	0.496	M2 W2 PR
0.165	MC M2 W2	0.517	MC BDW M2
0.232	MC W2 PR	0.605	BDW M2 PR
0.289	MC BDW M2	0.635	MC W2 PR
0.414	M2 W2 PR	0.644	MC W2 PR
0.466	MC BDW PR	0.649	MC M2 W2
0.753	BDW M2 PR	0.679	MC BDW PR
0.779	BDW W2 PR	0.913	BDW M2 W2
0.797	BDW M2 PR	0.915	MC BDW W2
0.839	MC BDW W2	0.916	BDW W2 PR
0.417	MC M2 W2 PR	0.652	MC M2 W2 PR
0.818	BDW M2 W2 PR	0.692	MC BDW W2 PR
0.878	MC BDW M2 PR	0.916	MC BDW M2 W2
0.881	MC BDW W2 PR	0.925	MC BDW M2 W2
0.968	MC BDW M2 W2	0.947	BDW M2 W2 PR
0.998	MC BDW M2 W2 PR	0.952	MC BDW M2 W2 PR

APPENDIX C

COMPARISON OF CALCULATED MOISTURE WITH THE MEAN OF EXPERIMENTAL VALUES

LIST OF VARIABLES IN APPENDIX C

IMC,	initial moisture content of the seed, %
MBAR,	mean experimental moisture content for a specific relative humidity at a specific purity and sorptive state, %
MOIST,	experimental moisture content, %
PURITY,	purity of the seed, %
RH,	relative humidity, %
STDEV,	the standard deviation from the mean of data at a specific RH, purity and sorptive state
XMOIST,	experimental moisture content, %
XXMOIST,	moisture content calculated using constants derived from analyses of all seed data regardless of state
YMOIST,	moisture content calculated using constants derived from analyses of seed data at a specific temperature and sorptive state at all purities

TABLE XIV

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES FOR DRY SEED AT 20C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	YMOIST	MBAR	STDEV
1	0.439	10.48	8.70	17.9	8.88	8.03	7.90	10.29	0.46
2	0.439	10.43	8.70	17.9	8.88	8.03	7.90	10.29	0.46
3	0.439	10.85	8.70	17.9	8.88	8.03	7.90	10.29	0.46
4	0.439	9.66	9.13	17.9	8.88	8.03	7.90	10.29	0.46
5	0.439	10.02	9.13	17.9	8.88	8.03	7.90	10.29	0.46
6	0.439	10.35	9.10	21.3	8.55	8.03	7.90	9.63	0.59
7	0.439	10.21	9.10	21.3	8.55	8.03	7.90	9.63	0.59
8	0.439	9.16	9.80	21.3	8.55	8.03	7.90	9.63	0.59
9	0.439	9.16	9.80	21.3	8.55	8.03	7.90	9.63	0.59
10	0.439	9.29	9.80	21.3	8.55	8.03	7.90	9.63	0.59
11	0.552	10.89	9.13	17.9	11.45	11.30	10.59	10.86	0.04
12	0.552	10.84	9.13	17.9	11.45	11.30	10.59	10.86	0.04
13	0.552	10.80	9.10	21.3	11.18	11.30	10.59	11.04	0.35
14	0.552	11.29	9.10	21.3	11.18	11.30	10.59	11.04	0.35
15	0.552	10.25	10.33	34.5	9.40	11.30	10.59	10.30	0.08
16	0.552	10.36	10.33	34.5	9.40	11.30	10.59	10.30	0.08
17	0.552	11.23	10.50	63.4	9.12	11.30	10.59	10.86	0.52
18	0.552	10.50	10.50	63.4	9.12	11.30	10.59	10.86	0.52
19	0.653	12.66	9.13	17.9	14.06	14.62	13.34	12.89	0.33
20	0.653	13.12	9.13	17.9	14.06	14.62	13.34	12.89	0.33
21	0.653	13.39	9.10	21.3	13.86	14.62	13.34	13.51	0.17
22	0.653	13.63	9.10	21.3	13.86	14.62	13.34	13.51	0.17
23	0.653	11.94	10.33	34.5	12.00	14.62	13.34	12.16	0.32
24	0.653	12.39	10.33	34.5	12.00	14.62	13.34	12.16	0.32
25	0.653	12.77	10.50	63.4	11.94	14.62	13.34	12.42	0.49
26	0.653	12.07	10.50	63.4	11.94	14.62	13.34	12.42	0.49
27	0.755	17.87	8.70	17.9	17.34	18.78	16.78	16.84	0.79
28	0.755	17.33	8.70	17.9	17.34	18.78	16.78	16.84	0.79
29	0.755	16.88	8.70	17.9	17.34	18.78	16.78	16.84	0.79
30	0.755	16.10	9.13	17.9	17.34	18.78	16.78	16.84	0.79
31	0.755	16.02	9.13	17.9	17.34	18.78	16.78	16.84	0.79
32	0.755	15.66	9.80	21.3	17.22	18.78	16.78	16.09	0.61
33	0.755	15.70	9.80	21.3	17.22	18.78	16.78	16.09	0.61
34	0.755	15.66	9.80	21.3	17.22	18.78	16.78	16.09	0.61

TABLE XIV

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES
FOR DRY SEED AT 20C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	YMOIST	MBAR	STDEV
35	0.755	17.01	9.10	21.3	17.22	18.78	16.78	16.09	0.61
36	0.755	16.40	9.10	21.3	17.22	18.78	16.78	16.09	0.61
37	0.755	14.54	10.33	34.5	15.25	18.78	16.78	14.61	0.11
38	0.755	14.69	10.33	34.5	15.25	18.78	16.78	14.61	0.11
39	0.755	14.58	10.50	63.4	15.47	18.78	16.78	14.62	0.06
40	0.755	14.67	10.50	63.4	15.47	18.78	16.78	14.62	0.06
41	0.866	23.49	20.90	10.6	23.08	25.48	22.31	22.96	0.74
42	0.866	22.44	20.90	10.6	23.08	25.48	22.31	22.96	0.74
43	0.866	20.37	9.13	17.9	22.61	25.48	22.31	20.53	0.23
44	0.866	20.69	9.13	17.9	22.61	25.48	22.31	20.53	0.23
45	0.866	22.31	9.10	21.3	22.62	25.48	22.31	22.47	0.23
46	0.866	22.64	9.10	21.3	22.62	25.48	22.31	22.47	0.23
47	0.866	19.03	10.33	34.5	20.48	25.48	22.31	19.13	0.14
48	0.866	19.23	10.33	34.5	20.48	25.48	22.31	19.13	0.14
49	0.866	18.04	10.50	63.4	21.14	25.48	22.31	18.49	0.64
50	0.866	18.94	10.50	63.4	21.14	25.48	22.31	18.49	0.64
51	0.935	30.58	20.90	10.6	30.93	33.09	28.60	30.68	0.15
52	0.935	30.79	20.90	10.6	30.93	33.09	28.60	30.68	0.15
53	0.935	29.42	8.70	17.9	28.61	33.09	28.60	29.14	1.37
54	0.935	30.67	8.70	17.9	28.61	33.09	28.60	29.14	1.37
55	0.935	29.93	8.70	17.9	28.61	33.09	28.60	29.14	1.37
56	0.935	27.12	9.13	17.9	28.61	33.09	28.60	29.14	1.37
57	0.935	28.54	9.13	17.9	28.61	33.09	28.60	29.14	1.37
58	0.935	28.25	9.80	21.3	28.76	33.09	28.60	29.08	1.52
59	0.935	27.68	9.80	21.3	28.76	33.09	28.60	29.08	1.52
60	0.935	28.05	9.80	21.3	28.76	33.09	28.60	29.08	1.52
61	0.935	30.97	9.10	21.3	28.76	33.09	28.60	29.08	1.52
62	0.935	30.47	9.10	21.3	28.76	33.09	28.60	29.08	1.52
63	0.935	27.00	10.33	34.5	26.43	33.09	28.60	27.19	0.28
64	0.935	27.39	10.33	34.5	26.43	33.09	28.60	27.19	0.28
65	0.935	28.58	10.50	63.4	27.59	33.09	28.60	28.79	0.30
66	0.935	29.00	10.50	63.4	27.59	33.09	28.60	28.79	0.30

TABLE XV

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES FOR WET SEED AT 20C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	YMOIST	MBAR	STDEV
1	0.232	8.08	47.8	10.6	5.63	2.30	4.25	7.75	0.30
2	0.232	7.49	47.8	10.6	5.63	2.30	4.25	7.75	0.30
3	0.232	7.68	47.8	10.6	5.63	2.30	4.25	7.75	0.30
4	0.232	7.50	42.6	17.9	4.20	2.30	4.25	7.31	0.26
5	0.232	7.42	42.6	17.9	4.20	2.30	4.25	7.31	0.26
6	0.232	7.02	42.6	17.9	4.20	2.30	4.25	7.31	0.26
7	0.232	6.64	46.8	21.3	2.56	2.30	4.25	6.35	0.62
8	0.232	5.66	46.8	21.3	2.56	2.30	4.25	6.35	0.62
9	0.232	7.00	46.8	21.3	2.56	2.30	4.25	6.35	0.62
10	0.232	5.65	46.8	21.3	2.56	2.30	4.25	6.35	0.62
11	0.232	7.00	46.8	21.3	2.56	2.30	4.25	6.35	0.62
12	0.232	6.15	46.8	21.3	2.56	2.30	4.25	6.35	0.62
13	0.232	9.46	78.6	30.0	6.86	2.30	4.25	9.09	0.41
14	0.232	9.15	78.6	30.0	6.86	2.30	4.25	9.09	0.41
15	0.232	8.65	78.6	30.0	6.86	2.30	4.25	9.09	0.41
16	0.439	10.45	47.8	10.6	11.20	8.03	10.48	10.52	0.25
17	0.439	10.31	47.8	10.6	11.20	8.03	10.48	10.52	0.25
18	0.439	10.79	47.8	10.6	11.20	8.03	10.48	10.52	0.25
19	0.439	10.39	42.6	17.9	10.72	8.03	10.48	10.61	0.20
20	0.439	10.65	42.6	17.9	10.72	8.03	10.48	10.61	0.20
21	0.439	10.78	42.6	17.9	10.72	8.03	10.48	10.61	0.20
22	0.439	7.52	46.8	21.3	9.23	8.03	10.48	8.61	0.65
23	0.439	8.98	46.8	21.3	9.23	8.03	10.48	8.61	0.65
24	0.439	8.78	46.8	21.3	9.23	8.03	10.48	8.61	0.65
25	0.439	9.42	46.8	21.3	9.23	8.03	10.48	8.61	0.65
26	0.439	8.33	46.8	21.3	9.23	8.03	10.48	8.61	0.65
27	0.439	8.62	46.8	21.3	9.23	8.03	10.48	8.61	0.65
28	0.439	12.44	78.6	30.0	12.17	8.03	10.48	11.56	0.77
29	0.439	11.22	78.6	30.0	12.17	8.03	10.48	11.56	0.77
30	0.439	11.01	78.6	30.0	12.17	8.03	10.48	11.56	0.77
31	0.755	19.31	47.8	10.6	21.63	18.78	22.17	19.17	0.13
32	0.755	19.05	47.8	10.6	21.63	18.78	22.17	19.17	0.13
33	0.755	19.14	47.8	10.6	21.63	18.78	22.17	19.17	0.13
34	0.755	18.45	42.6	17.9	22.93	18.78	22.17	18.42	0.27

TABLE XV

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES FOR WET SEED AT 20C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	YMOIST	MBAR	STDEV
35	0.755	18.68	42.6	17.9	22.93	18.78	22.17	18.42	0.27
36	0.755	18.14	42.6	17.9	22.93	18.78	22.17	18.42	0.27
37	0.755	17.86	46.8	21.3	21.72	18.78	22.17	17.78	0.59
38	0.755	16.73	46.8	21.3	21.72	18.78	22.17	17.78	0.59
39	0.755	17.95	46.8	21.3	21.72	18.78	22.17	17.78	0.59
40	0.755	17.68	46.8	21.3	21.72	18.78	22.17	17.78	0.59
41	0.755	18.55	46.8	21.3	21.72	18.78	22.17	17.78	0.59
42	0.755	17.92	46.8	21.3	21.72	18.78	22.17	17.78	0.59
43	0.755	20.00	78.6	30.0	22.12	18.78	22.17	19.48	0.47
44	0.755	19.36	78.6	30.0	22.12	18.78	22.17	19.48	0.47
45	0.755	19.08	78.6	30.0	22.12	18.78	22.17	19.48	0.47
46	0.935	36.89	47.8	10.6	35.52	33.09	37.72	36.55	0.68
47	0.935	35.76	47.8	10.6	35.52	33.09	37.72	36.55	0.68
48	0.935	36.99	47.8	10.6	35.52	33.09	37.72	36.55	0.68
49	0.935	39.09	42.6	17.9	39.19	33.09	37.72	40.57	1.50
50	0.935	42.08	42.6	17.9	39.19	33.09	37.72	40.57	1.50
51	0.935	40.55	42.6	17.9	39.19	33.09	37.72	40.57	1.50
52	0.935	33.92	46.8	21.3	38.36	33.09	37.72	39.13	4.91
53	0.935	37.50	46.8	21.3	38.36	33.09	37.72	39.13	4.91
54	0.935	40.30	46.8	21.3	38.36	33.09	37.72	39.13	4.91
55	0.935	36.76	46.8	21.3	38.36	33.09	37.72	39.13	4.91
56	0.935	48.22	46.8	21.3	38.36	33.09	37.72	39.13	4.91
57	0.935	38.10	46.8	21.3	38.36	33.09	37.72	39.13	4.91
58	0.935	36.78	78.6	30.0	35.37	33.09	37.72	36.40	0.35
59	0.935	36.10	78.6	30.0	35.37	33.09	37.72	36.40	0.35
60	0.935	36.33	78.6	30.0	35.37	33.09	37.72	36.40	0.35

TABLE XVI

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES FOR DRY SEED AT 32C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	YMOIST	MBAR	STDEV
1	0.540	9.16	9.01	17.9	12.71	10.93	11.14	9.65	0.40
2	0.540	9.54	9.01	17.9	12.71	10.93	11.14	9.65	0.40
3	0.540	9.78	9.01	17.9	12.71	10.93	11.14	9.65	0.40
4	0.540	10.12	9.01	17.9	12.71	10.93	11.14	9.65	0.40
5	0.650	11.17	9.01	17.9	15.05	14.51	13.48	11.82	0.55
6	0.650	12.52	9.01	17.9	15.05	14.51	13.48	11.82	0.55
7	0.650	11.73	9.01	17.9	15.05	14.51	13.48	11.82	0.55
8	0.650	11.85	9.01	17.9	15.05	14.51	13.48	11.82	0.55
9	0.780	17.88	16.80	10.6	18.30	20.01	17.07	17.82	0.20
10	0.780	17.60	16.80	10.6	18.30	20.01	17.07	17.82	0.20
11	0.780	17.99	16.80	10.6	18.30	20.01	17.07	17.82	0.20
12	0.780	14.60	9.01	17.9	18.64	20.01	17.07	14.90	0.30
13	0.780	15.20	9.01	17.9	18.64	20.01	17.07	14.90	0.30
14	0.780	14.91	9.01	17.9	18.64	20.01	17.07	14.90	0.30
15	0.920	26.89	16.80	10.6	25.25	30.93	24.21	25.76	1.26
16	0.920	25.98	16.80	10.6	25.25	30.93	24.21	25.76	1.26
17	0.920	24.40	16.80	10.6	25.25	30.93	24.21	25.76	1.26

TABLE XVII

COMPARISON OF CALCULATED MOISTURE WITH MEAN EXPERIMENTAL VALUES FOR WET SEED AT 32C

OBS	RH	MOIST	IMC	PURITY	XMOIST	XXMOIST	MBAR	STDEV
1	0.230	7.30	47.8	10.6	4.71	2.24	6.95	0.49
2	0.230	6.61	47.8	10.6	4.71	2.24	6.95	0.49
3	0.360	8.96	47.8	10.6	7.87	5.88	8.61	0.49
4	0.360	8.26	47.8	10.6	7.87	5.88	8.61	0.49
5	0.460	10.91	47.8	10.6	10.26	8.62	10.57	0.47
6	0.460	10.24	47.8	10.6	10.26	8.62	10.57	0.47
7	0.590	12.71	47.8	10.6	13.62	12.48	12.52	0.27
8	0.590	12.33	47.8	10.6	13.62	12.48	12.52	0.27
9	0.650	13.96	47.8	10.6	15.38	14.51	13.60	0.51
10	0.650	13.24	47.8	10.6	15.38	14.51	13.60	0.51
11	0.720	15.42	47.8	10.6	17.74	17.22	15.18	0.34
12	0.720	14.94	47.8	10.6	17.74	17.22	15.18	0.34
13	0.850	26.53	47.8	10.6	23.86	24.26	25.51	1.44
14	0.850	24.50	47.8	10.6	23.86	24.26	25.51	1.44

VITA

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