Management strategies for corn production and drying systems

Din-Sue Fon

Iowa State University

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Management strategies for corn production and drying systems

by

Din-Sue Fon

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INTRODUCTION

CORNSIM and FALDRY are deterministic models which were developed by Van Ee and Kline (1979a, b) to simulate a complete corn production management system for past years.

The main function of CORNSIM is to supply its simulated results of harvested grain flow data to FALDRY for corn drying and storage studies. With a proper scheme set up by the user, the model can predict the quantity and moisture content of the harvested corn, with corresponding date, on a daily basis. Information such as dates of planting, silking and maturity as well as yield damage due to frost and harvest operation is also provided.

FALDRY, on the other hand, simulates a complete farm drying system using ambient air with or without supplemental heat. The model functions with user-specified drying facilities—grain bins, fans, and loading capacities.

In their original forms, both the CORNSIM and FALDRY models were designed to be run separately. Inconvenience consequently arises when an optimum controlled-filling strategy is going to be applied since the results of the drying in bins cannot be immediately fed back to the decision procedure on harvest.

A revised model will be developed in this study by combining these two models so that the harvest operation can be constrained by four parameters, namely, the preset harvesting date, the corn moisture in the field, fieldwork conditions, and the potential capacity of the drying system. The new model will be more flexible for different management
strategies, but will still keep the same functions and output data as the old models did.

The field working condition is judged by the trafficability of farm machinery on the field. In the Van Ee and Kline CORNSIM model (1979a), field workdays were directly taken from observed records, which, very often, are not available for all locations and times. A model is needed to predict the desired field workdays from local weather data.

Management of a low temperature drying system appears to be an easy task but, in fact, it needs more care than high air temperature drying methods so far as spoilage is concerned. Many researchers, on the basis of the restrictions of spoilage, developed various filling strategies to optimize operation. Following this trend, a controlled-filling strategy is designed making use of a low temperature drying scheme to let the farmer harvest and dry his grain as fast as possible without causing any spoilage. The quantity of grain harvested in this scheme will depend on the airflow rate in drying bins.

Van Ee and Kline (1979a, b) used CORNSIM and FALDRY models accompanied by an optimum controlled-filling strategy to examine a corn production system for central Iowa and found that predictions of corn growth and drying results were close to the actual conditions from 1958 to 1975. The purpose of this study is to combine and modify the CORNSIM and FALDRY models and develop a new model for predicting the corn production, harvesting and drying operations for a 300-acre farm in northwestern Iowa using weather data of Sioux Falls from 1960 to 1979.
LITERATURE REVIEW

Field Workday Predictions

The field workday is a day when soil is suitable for operation of field machinery. In Van Ee and Kline's (1979a, b) model, field workdays were collected directly from the observed reports of the Iowa Crop and Livestock Reporting Service. However, because this information was only reported by weekly summaries, difficulty arose in applying it to a daily-basis model. Van Ee and Kline (1979a) distributed these weekly sums into each of seven days in a certain way. It was simple but still appeared to be a crude method and might carry unexpected variations into the CORNSIM model. To improve the accuracy of both models, a new prediction approach on field workdays is then justified.

Field Workdays

Prediction of field workdays has been done by many researchers for various purposes, which basically fall into three categories—finding probabilities for a certain sequence of field workdays (Hayhoe and Baier, 1974), finding recurrences of field workdays in a given period (Fulton et al., 1976, Parsons and Doster, 1982), and seeking go or no-go field conditions for calendar periods (Rosenberg et al., 1982, Morey et al., 1971b). Most of these works, more or less, were based on a certain type of soil moisture budget (Holmes and Robertson, 1959; Shaw, 1963), which described the soil moisture changes as a function of some weather parameters.
Hayhoe and Baier (1974) worked out a program to estimate the parameters for a Markov chain probability model from sequential data. A program was applied to an analysis of field workday probabilities at 10 selected locations across Canada. Results of the probabilities demonstrated a very strong dependence of working conditions on a given day on the previous day's condition. Using the same technique, Baier (1973) estimated average and probable field workdays during selected periods on the basis of both calendar time and development stage of the wheat crop across Canada.

Fulton et al. (1976) summarized sixteen years of weekly reports of field workdays from the Iowa Crop and Livestock Reporting Service and turned out a series of expected field workdays by weekly periods of a year at given probabilities. Results showed that the expected number of suitable days for the planting period decreased from north to south, and from west to east of Iowa. More specifically, the greatest decrease occurred from northwest to southeast.

To determine the number of workdays available at a specific probability level for multiweek periods, Hayhoe (1980) derived an algorithm and demonstrated its application on conversion of data reported from Fulton et al. (1976) to any desired subperiod.

The field workday probabilities estimated from the above methods may be of benefit to the farmers or managers who make proper system selections and schedule men and machines during the crop seasons (Fulton et al., 1976).
Evapotranspiration

Evapotranspiration (ET) is the loss of soil moisture due to evaporation from soil surface and transpiration through the plant. ET is an important parameter in constructing a soil moisture budget. Numerous methods available for estimating the evaporation can be found in the literature (Baier and Robertson, 1965; Holmes and Robertson, 1963; Pierce, 1960; Shaw, 1963; Saxton et al., 1974). However, most of these methods are often slow and subject to error (Pierce, 1960).

Using mean temperature and rainfall as the sole meteorological inputs, Pierce (1960) proposed an estimation method of finding evaporation for meadow crops. A term—potential evapotranspiration (PE) is usually used to indicate the maximum water loss due to evapotranspiration when soil moisture is plentiful. In Pierce's study (1960), the potential evapotranspiration (PE) was first estimated directly from the mean daily temperature and then corrected by length of day, crop stage, soil dryness, and rain condition to obtain the actual ET. This simple method, as Pierce has mentioned, worked successfully for meadow crops.

By employing multiple linear correlation and regression analysis, Baier and Robertson (1965) estimated daily latent evaporation from simple meteorological observations and astronomical data from climatological records. The results showed that with observations of only maximum and minimum temperatures available and extraterrestrial radiation from tables, the correlation coefficient with latent evaporation could reach 0.68 and could also reach 0.81 if additional
variables such as wind velocity, daylength, vapor pressure deficit, etc., were all included.

It is apparent that prediction of actual ET from PE is kind of an art and is of great difficulty. Holmes and Robertson (1963), working on wheat, intended to build up a relationship of this nature among the actual ET, PE and soil moisture contents. From their experiment conducted in a growth chamber, they found an initial plateau existing where the actual ET equals PE as soil moisture decreases. This is followed by a period of very rapid decrease in actual ET, which is exponential in shape.

On the other hand, Saxton et al. (1974) developed a simulation model, incorporating numerous meteorologic data on a relationship of crop growth and soil moisture on a daily basis throughout the year, to predict daily actual ET and soil moisture profiles for corn and grass crops. Interception evaporation, soil evaporation, plant transpiration and Shaw's soil moisture budget were all included in their model.

The Versatile Budget was first developed by Baier and Robertson (1966). Baier (1973) further used this moisture budget to estimate daily soil moisture in six or fewer zones from standard climatic data such as air temperatures and precipitation.

In a simulation model for predicting available days for soil tillage, Elliott et al. (1977) used a simple approach in calculating actual ET by simply making it equal to half of the potential value if precipitation was measurable that day and equal to the PE value if there was soil water remaining in the upper layer of soil. They also found
that evaporation was dependent upon the amount of soil cover provided by
crop residues. It was then assumed that the rate of evaporation
decreases linearly as the percentage of surface cover increases up to
100 percent. For an extreme case, the maximum amount of cover will cut
down the actual ET to 50% of the PE value.

Net radiation was also used to estimate PE as it was the primary
source of energy for evaporation. Selirio and Brown (1972) estimated
the PE by making it equal to 80% of net radiation when daytime mean
temperature was equal to or greater than 77°F and then letting it
decrease in a logarithmic manner below 77°F to nil at 32°F. The actual
ET of soil moisture from each zone was assumed equal to or greater than
95% and followed an exponential decay when the available moisture was
less than 95% (Holmes and Robertson, 1959, 1963).

In the model of Rosenberg et al. (1982), the ET was estimated from
open pan evaporation and the PE was set at 55% of open pan evaporation
until June 30th and 75% for the time thereafter. Both percentages were
determined empirically, however.

Criteria of Field Workdays

A soil is considered tractable if a tractor or other farm machine
can move on that soil to satisfactorily perform the function of the
machine, without a significant damage to the soil (Hassan and Broughton,
1975). Most soil is tractable at moistures near or below field
capacity. Shaw (1965) considered a day workable if the soil moisture
was less than 0.75 in. out of a 6 in. soil layer. On the other hand,
Maunder et al. (1971a, b) classified a workday as one in which soil
moisture was less than 1.76 in. out of 12 in. soil profile.

For the purpose of cultivation operations, Selirio and Brown (1972) suggested for a loam soil that 90% of the field capacity for a depth of 4.72 in. could be considered tractable if daily snowfall was less than 1 in. and maximum air temperature was above 32°F. Rutledge and McHardy (1968) used a simplified version of the versatile budget for estimating field workdays. They considered the day to be not workable if the estimated soil moisture was in excess of 95% of field capacity in any of three upper layers. However, Baier (1973) considered that 97.5% of field capacity for the top three layers was a good criterion for heavy machinery and deep cultivation for dry conditions.

Hassan and Broughton (1975) studied three kinds of soil—fine sandy loam, clay loam, and clay and found that the two top layers (0-1 in. and 1-3 in.) were most sensitive to the decision of field workdays. Tractability criteria for seedbed preparation were also presented for different types of soil in their study.

Moisture Budget

The budgeting technique reflects soil moisture changes as a function of precipitation including snowmelt, PE, runoff, percolation, preceding soil moisture content, drainage rate, crop characteristics and etc. (Hayhoe and Baier, 1974; Shaw, 1963).

There are numerous such soil moisture budgets in use today, namely, a modulated soil moisture budget as developed by Holmes and Robertson (1959), a versatile soil moisture budget as proposed by Baier and Robertson (1966), and an estimated soil moisture budget under corn as
presented by Shaw (1963).

To describe the water movements in a soil layer, the soil profile was usually divided into several zones. However, researchers shared different opinions on the thickness and number of the soil layers they used. Some of them only considered one zone with a depth from 6 in. to 12 in. (Shaw, 1965; Maunder et al., 1971a, b). Some used two zones with one thin and another thick (Dyer and Baier, 1979; Elliott et al., 1977). Rosenberg, et al. (1982), on the other hand, used three zones in their model.

However, most researchers who employed the soil budget to calculate the stress index or to predict the crop yields adopted a soil profile of five zones (Hassan and Broughton, 1975; Baier and Robertson, 1966; Selirio and Brown, 1972; Shaw, 1963, 1977).

Maunder et al. (1971a, b) developed a simplified model to predict the workdays for road construction. The model was applied to a long-term series of daily precipitation records to calculate the road construction condition over a period of 1918-1965. The soil moisture was calculated by subtracting water loss due to drainage and runoff from precipitation. Since values of both precipitation and water loss in their model were quite empirical, it could hardly be applied on conditions except those of the Missouri area if a reasonable accuracy was needed.

Shaw (1965) worked out a prediction model for field working days for spring in Iowa. The results were then compared with actual records kept at the ISU Agronomy Farm, Ames, Iowa. Judging by the results, he
found that the correlation between observed and predicted numbers of working days was 0.86 in March and 0.88 for both April and May.

Most of soil budgets were calculated on a daily basis. However, Elliott et al. (1977) found that the moisture balance model appeared to be less accurate in field workday prediction on a daily basis. They concluded that the model would become reasonably accurate and useful if run on a monthly basis.

In the versatile moisture budget, moisture exchange between two pre-divided zones by diffusion was also considered by Dyer and Baier (1979). In this model, each zone was allowed to contain gravity water for a short period of time. They discovered that the range of soil moisture from permanent wilting point to complete saturation varied only slightly between clay and sandy soils. Therefore, the total void space in this model was considered to be independent of soil type.

Low Temperature Drying

A low temperature drying usually refers to a drying process which dries the grain as slowly as possible without spoilage. The drying air can be electrically heated, solar-heated, or heated by other means. Interest in low-temperature drying has grown since 1950s. With the rapid depletion of fossil fuels and gradual increase of expense for conventional high temperature dryers, a low temperature drying method becomes more acceptable in recent years (Kranzler, 1977).
Advantages and Disadvantages

Advantages of low temperature drying include:

1. Relatively simple system equipment requirements and less cost (Foster, 1953; Kranzler, 1977).
3. Good quality grain—few stress cracks and high test weight (Bakker-Arkema et al., 1978; Brown et al., 1979; Otten and Brown, 1982).
4. Less dependent on petroleum based fuels (Brown et al., 1979; Midwest Plan Service, 1980).
5. High drying efficiency because it uses atmospheric heat (Morey and Peart, 1971).
6. Flexible harvest rate and time (Brooker et al., 1974).
7. Less fire hazard than in high temperature drying (Foster, 1953).

However, disadvantages include:

1. Initial moisture content limitations (Midwest Plan Service, 1980).
2. High electrical power demand of fan and heater and limitation on the system size (Kranzler, 1977).
3. Weather dependency and slow drying process (Sharp, 1982; Fraser and Muir, 1980).
4. Possible limitation on filling rate.
5. Possible delay of the management period due to longer drying time (Brooker et al., 1974; Van Ee and Kline, 1979b).
6. Limitation on the availability of drying and (or) storage facilities on a single crop (Kranzler, 1977).

7. Grain spoilage resulting from improper management (Kranzler, 1977; Pierce and Thompson, 1979).

Airflow Rates

Topics related to the basic principle of low temperature drying can be found in the literature (Hukill, 1947; Kranzler, 1977; Howe, 1980; Harrison, 1969; Bakker-Arkema et al., 1978). According to Bloome and Shove (1972), a low temperature drying process is dependent on airflow rate, harvest moisture content, amount of heat added, harvest date and variability of weather. Airflow rate is the deciding factor in managing a low temperature drying system. The minimum airflow rate for drying grain with unheated air is largely dependent on an acceptable limit on grain deterioration.

Foster (1953) found that 3 cfm/bu would be quite adequate for drying shelled corn from 25% to 15.5% in a moderate fall weather in Indiana. For aeration purposes, Rabe (1958) found that 0.3-0.4 cfm/bu was the suitable range. Holman (1955), for aerating the stored grain, utilized even smaller air flow rate of 1/30-1/40 cfm/bu. It is interesting to note that during the aeration period most of the grain cooling was caused by the cooling effect of the water evaporated from the grain (Rabe, 1958).

For the midwestern area, the minimum airflow rate for a full-bin drying increases from the northwest (North Dakota) to the southeast (Illinois) from 1 cfm/bu to 1.5 cfm/bu (Midwest Plan Service, 1980).
Figure 1 shows the distribution of required airflow rate and corresponding harvest moistures for this area.

Shove (1976), on the other hand, worked on a low temperature drying system and set up guidelines for airflow rates for the midwestern United States. He recommended an airflow rate of 2 cfm/bu of grain for corn harvested at 24% moisture content and 3 cfm/bu of grain for an initial moisture content of 26%. The drying time for these airflow ranges is about 3-4 weeks. However, supplemental heat of 4-9°F above ambient air might be needed to increase the drying potential of air during periods of adverse weather conditions (Shove, 1976).

Van Ee and Kline (1979b) and Shove (1981) recommended to speed the drying process by increasing the fan horsepower rather than by adding supplemental heat. Morey and Peart (1971) suggested that to dry grain by blowing large amounts of natural air through the system might be economical since under most natural air state conditions, some potential for drying exists. Bloome and Shove (1972) also made the same conclusion. A greater airflow rate could keep expected grain deterioration at a low level.

The quality of corn dried with a low temperature system was high (Brown et al., 1979). Thompson (1972) concluded from a computer simulation study of low temperature corn drying that deterioration of grain was doubled as airflow was halved in the range of 0.5-2 cfm/bu and also doubled for each 2% increase in initial moisture content in the range of 20-25%. However, this deterioration rate would be halved for each 15-day delay in harvest date from Oct. 1 to Nov. 15 but was
FIGURE 1. Recommended full-bin airflow rate for fan selection and maximum corn moisture contents for single-fill drying (source: Midwest Plan Service, 1980).
independent of grain temperature at the date of harvest.

Harner et al. (1981a) used high airflow rate of low temperature air to dry a thin layer of corn. They suggested that the moisture of corn should be reduced from 20%-13% within 12 hours so that the chances of spoilage or aflatoxin contamination will be eliminated. Shove and Andrew (1969) conducted an experiment on aeration fan control and found that continuous operation of a fan supplying about 0.5 cfm/bu reduced the moisture content from 23% to 15.8% in 120 days without any quality discount.

Pierce and Thompson (1980a), using Thompson's model with the basis of 0.5% dry-matter loss, determined minimum airflow requirements for natural air or low temperature drying systems for various combinations of harvest date and initial moisture content. The effects of adding supplemental heat were studied for a wide range of conditions. They commented that the major problems associated with low temperature drying were the high airflow rates required for corn harvested at high moisture content (especially when harvested early) and the excessive overdrying which occurred with the addition of supplemental heat.

Employing a simulation technique, Fraser and Muir (1981) found that the airflow requirements increased from the northwest to the southeast of Canada and decreased by approximately 50% for each month's delay in harvest but approximately doubled for each 2% increase of the harvest moisture content.
Quality of Corn

Grain quality is a factor which concerns most researchers who study grain drying and storage systems and also farmers who are in need of selecting a proper dryer or drying system. There are three kinds of criteria in use to predict grain deterioration: namely, carbon dioxide production (Saul and Lind, 1958; Steele, 1967; Steele et al., 1969; Fawole, 1969; Alejandro et al., 1982), microflora activity (Ross et al., 1979; Saul, 1960) and seed viability (Sharp, 1982). Generally speaking, these three phenomena are closely related, but because the germination or viability may still remain high even when significant deterioration has taken place, many researchers adopt the first or the second criterion of grain deterioration.

Grain deterioration usually limits the total time the undried grains can be allowed in a dryer and, consequently, increases the required airflow rate in a drying system (Saul and Lind, 1958). Foster (1953) further confirmed from his study that the amount of grain deterioration during drying was closely associated with the length of the drying period and the temperature of the drying air.

Saul and Lind (1958), on the basis of the active mold growth and CO₂ production during storage, investigated the allowable drying time for a natural air drying system and discovered that the deterioration rate might be six to eight times greater for high moisture corn above 25% than for low moisture corn below 22%. In numerous laboratory-scale tests, Saul (1960) concluded that the microflora associated with shelled corn was directly related to the average wet bulb air temperature, corn
moisture, and degree of mechanical damage.

Similarly, by using the mold-time limitation curves, Teter and Roane (1958) proposed an equation to estimate the airflow rate to avoid possible spoilage. The equation based on a heat balance between heat supplied from drying air and heat used in drying can be expressed as follows:

\[
0.24 \times Q \times D \times T = W \times H
\]

in which, 
- **Q** = airflow rate, lb of dry air/min/bu.
- **D** = average temperature depression through the bin, °F.
- **T** = allowable time to dry to 15.5% to prevent excessive mold growth, min.
- **W** = pounds of water to be removed to reduce one bushel to 15.5% moisture.
- **H** = latent heat of evaporation, Btu/lb of water.

0.24 = specific heat of air, Btu/lb.

The relationship among deterioration rate, moisture content and temperature of grain was further developed by Steele et al. (1969). By using a CO\textsubscript{2} production technique, they found that corn with a moisture of 25% and a mechanical damage of 30% exposed to an air of 60°F for 230 hours would decompose 0.5% of its dry matter but still maintain its market value. Corn with a dry-matter loss of more than 0.5% will be counted down one grade. All other conditions were then adjusted to this reference point for comparisons by using correction factors related to
temperature, moisture and mechanical damage of corn. These relationships, later updated by Saul (1970) on the temperature effect, were further summarized by Thompson (1972) and will be employed for this study.

Flood et al. (1972), however, used a different approach to directly find the actual storage time. They applied a temperature-time-moisture curves in a form of equation like this:

\[ t = a T^{-b} \]

where \( T = \) grain temperature, °F.
\( t = \) storage time, hours.
\( a, b = \) constants.

Obviously, deterioration of grain quality from the farmer's field to the processor depends on moisture content, temperature, kernel damage, foreign material and length of storage time (Kabernick and Muir, 1979). From field observations, Kabernick and Muir (1979) found that, for a low temperature drying system, the cost of controlling this deterioration was determined by the equipment to dry, clean and store the grain whether these operations were done on or off the farm.

Pierce and Thompson (1979) discovered, from their experiment on drying, that the greatest spoilage usually occurred on the top layer in a drying bin with single-fill loading. Therefore, minimum airflow requirements were largely determined by the condition of the grain in this layer.
Harner et al. (1981a) developed a parametric model of corn spoilage for humid regions to determine the drying state of the corn using low temperature drying. A linear dry-spoil equation was also developed. This parametric model predicted correct results in 391 of 593 simulated drying seasons, for an overall accuracy of 66%.

Ross et al. (1979) studied aflatoxin development in low temperature drying systems. The previous data showed that common storage fungi grew most rapidly at temperatures of 85-90°F but below 55°F toxin production ceased and growth of the fungi was very slow at 35°F to 40°F. In their study, Thompson's equilibrium grain drying model was used to simulate the temperature and relative humidity in a grain mass during low temperature drying. They assumed that aflatoxin would develop in the top layer of grain when equilibrium relative humidity was above 85% and temperature was in the range of 55.4°F to 105.8°F for more than 48 hours. The results showed a definite potential for aflatoxin development in low temperature drying systems during the normal harvest period in the southern United States.

In studying the effect of a high-low temperature drying method, Gustafson et al. (1976) and Otten and Brown (1982) found that combination drying caused less susceptibility to mechanical damage, less reduction in germination rate and greater increase in test weight than conventional high temperature drying. Results of Gustafson et al. (1976) also indicated that the product of heat time and change of moisture content could be the best predictor of decrease in germination during high temperature drying.
Sometimes, the quality of grain could be maintained during drying by using other techniques. Sabbah et al. (1979a), using periodic reversal of airflow direction to dry soybeans, found that the final moisture uniformity and the seed quality were improved. These results were confirmed by Fon (1981) in his study on drying paddy rice. Paulsen and Thompson (1973), on the other hand, employed the same technique on a high temperature dryer.

Energy Consumption

The recent emphasis on energy conservation leads to an increase of interest in improving efficiency of design and operation of grain dryers (Morey et al., 1976a, b). Many researchers (Brooker et al. 1974; Converse, 1972; Morey and Cloud, 1973; Morey et al., 1976a, b, 1981) made efforts in designs or modifications of high and high-low temperature dryers to reduce energy requirements. Young and Dickens (1975) and Loewer et al. (1981) focused on energy requirements for batch and crossflow dryers. For the low temperature drying system, numerous combinations of drying schemes have been tested for the same purposes (Mittal and Otten, 1981; Van Ee and Kline, 1979b; Morey et al., 1976a, b; Pierce and Thompson, 1980a, b).

In principle, a low temperature drying system may require less purchased energy than the latent heat of evaporation of water --1075 Btu/lb water removed -- to remove moisture from grain because of the potential drying capacity of ambient air. In reality, the energy consumption is very dependent on climate. Fraser and Muir (1980) found that an average of 653 Btu/lb of water removed was needed in a semi-arid
region compared with an average of 1032 Btu/lb of water removed in a humid region, for wheat.

During a good year like 1976 in Toronto, the energy consumption calculated by Mittal and Otten's method (1982) was low as 344 Btu/lb of water removed but for poor years like 1971 and 1972, the figure could be as high as 3353 Btu/lb of water removed, with corn at an initial moisture of 22% being dried down to 14.5%.

Morey et al. (1978) reported that specific energy consumption for combination treatments was generally 1290 Btu/lb of water removed at 1.0 cfm/bu. However, Otten and Brown (1982) reported that a range of 1720 to 2407 Btu/lb of water removed was required for a low temperature drying system. This is not significantly less than that of a conventional high temperature drying system, in which energy consumption was reported in a range of 1290 to 1720 Btu/lb of water removed (Sharp, 1982).

A few tests conducted on radial bin, floor ventilated bin and on-floor low temperature dryers by NIAE showed that 1390 Btu/lb water removed was required for drying radial bins at an average relative humidity of 79%, and 1569 Btu/lb of water removed for floor ventilated and on-floor bins, respectively, at an average relative humidity of 80% (Sharp, 1982).

Using a controlled filling procedure and simulated harvested data, Van Ee and Kline (1979a, b) found that average energy consumption was about 1247 Btu/lb water removed, with an ideal year requiring about half this figure and a poor year requiring about twice this value.
Morey et al. (1979a) simulated energy requirements using several management strategies. For the Des Moines area, with an airflow rate of 1 cfm/bu in a grain bed of 16 ft for a single-fill bin drying corn from 20.7% to 13.4%, the energy requirement for continuous fan operation ranged from 434 to 713.6 Btu/lb of water removed for harvest dates from Oct. 1 to Nov. 1. However, by using delayed filling at a 10-day interval, this energy requirement dropped to a range of from 413 to 656 Btu/lb of water removed, or decreased by 5%-8%.

Two humidistat control strategies, as reported by Morey et al. (1979a), gave savings of 14%-20% in energy for corn harvested on Oct. 1. However, the same authors recommended that continuous fan operation was preferable for a low temperature drying system since an increase in deterioration and overdrying appeared to outweigh the advantages of savings in energy requirements.

Interestingly enough, low temperature drying seems unlikely to compare favorably with efficient high temperature drying (Sharp, 1982), from an energy utilization viewpoint. Since electricity is a kind of "high quality" energy, the values for electricity consumption have to be multiplied by a factor of about 4 to account for losses in generation.

Colliver et al. (1979), using operational research techniques in minimizing the total energy for drying by selecting different drying modes, found that the maximum effective total heat change at each time step was a good indicator of the optimal solution. This quantity was defined as: (sensible heat at the end of the time step) - (sensible heat at the beginning of the time step) + (latent energy used in evaporation
of water) - (latent energy of rewetting) - (electrical energy input).

Using the technique they developed, they found that the energy saving of switching modes compared to continuous fan operation were 19% for the natural air drying system, 23% for the solar drying system, 56% for the electrical drying system, 45% for the electrical drying system using off peak power rates and 51% for the natural air drying system using stirring devices. They also found that using relative humidity and time of day as switching parameters would save 14% to 49% and 7% to 29% respectively in energy consumption.

Data collected on a low temperature corn drying bin by Shove (1981) indicated that energy could be more efficiently used by increasing airflow rate, rather than increasing the temperature of drying air. Results also indicated that energy could be conserved by controlling bin filling to keep the airflow relatively high and by mixing grain to achieve a more uniform moisture content once an acceptable average was reached.

**Low Temperature Drying Models**

There are four general approaches in analyzing and characterizing deep-bed drying: logarithmic models, nonequilibrium models, equilibrium models and combined models. Nonequilibrium models employ more complex partial differential equations in which four balance equations for mass, heat, heat transfer and drying rate were solved with numerical techniques (Sharp, 1982; Kranzler, 1977). Strictly speaking, the other models are special cases of nonequilibrium models and tend to be of an empirical or semi-empirical nature (Sharp, 1982).
Logarithmic Models  The first serious attempt to model deep-bed grain drying was made by Hukill (1954). By neglecting the sensible heat of grain and of the removed moisture in the heat balance equation, Hukill developed a logarithmic model which simulated moisture contents and temperatures of grain at any level at any time.

Later, this model was analytically modified by Hamdy and Barre (1970) and was applied to a low temperature deep bed drying of corn (Barre et al., 1971; Baughman et al., 1971). Subsequently, Barre and Hamdy (1974) used the same model to investigate optimal filling rates of bin drying. It was found to be very simple to use analytically or graphically for deep bed drying with constant input conditions of drying air.

Sabbah et al. (1979b), on the other hand, improved the same model by incorporating a velocity effect and allowing for time-varying inlet conditions in drying shelled corn. They considered this model capable of predicting average moisture history without significant loss in accuracy. However, Sharp (1982) commented that this model was not very accurate and not very suited to dynamic weather and airflow conditions.

By using the Hukill method, a computerized model was employed by Schroeder and Peart (1967) to simulate a dynamic dryer column. They found that the lower the grain flow rate, the greater the improvement in total moisture removal rate.

Nonequilibrium Models  The first study of deep-bed grain drying by using a digital computer in solving model balance equations was by Boyce (1966). He concluded that results were in reasonable agreement
with experimental observations.

Henderson and Henderson (1968) also proposed a computational procedure for deep bed drying by using a simulation technique. The MSU model developed by Bakker-Arkema et al. (1974) was a typical nonequilibrium model. A similar model was also presented by O'Callaghan et al. (1971).

Fortes and Okos (1980, 1981) employed a capillary theory instead of liquid diffusion that was adopted by many researchers (Pabis and Henderson, 1961, 1962; Henderson and Pabis, 1961; Chittenden and Hustrulid, 1966; Chu and Hustrulid, 1968; Henderson, 1974), and developed a set of transport equations which incorporated most of the existing models by combining both the mechanistic and the irreversible thermodynamic approaches to heat and mass transfer in porous media and corn kernels.

Models using this approach have been shown to be more accurate than earlier thin layer models, but require more computing time and therefore are not suitable for operational research applications (Sharp, 1982).

Many attempts have been made to reduce this computing time. Thompson et al. (1968) proposed a semi-empirical model, assuming that both air and grain temperatures were equal to an equilibrium temperature as soon as drying air was blown into a specific layer. The algorithm became simpler in this arrangement because those efforts in solving differential equations were dropped.

By using a diffusion equation, Sharaf-Eledern et al. (1979) developed an accurate, yet easy, mathematical model to describe the
behavior of fully exposed shelled corn and compared the results with those of logarithmic and diffusion models.

**Equilibrium Models**

In equilibrium models, it is assumed that a true equilibrium condition exists between the drying air and the grain in each layer during each time period. However, it is believed that this equilibrium might be achieved only for low temperature, low airflow grain drying (Sharp, 1982; Mittal and Otten, 1982).

By assuming that there was no hysteresis between absorption and desorption of moisture contents by the grain and that in each time interval the final equilibrium temperature fell between the initial grain and air temperatures, Bloome and Shove (1971) developed an equilibrium model in which one of four processes—heating and drying, heating and wetting, cooling and drying and cooling and wetting was selected by comparing the inlet air temperature with that of the grain.

The equilibrium model developed by Bloome and Shove (1971) was further simplified by Thompson (1972) in terms of three basic equations for heat, mass and equilibrium moisture balances. A computer searching technique was also used to obtain an iterative solution for the three unknowns—air temperature, humidity and final moisture—in the model. However, Pfost et al. (1977) tested Thompson's model against data from six experiments and found the model inadequate for three hour intervals of drying. They found that Thompson's model performed best with a time interval of 24 hours for loop calculations.

**Combined Models**

Discussions by Sharp (1982) indicate that the assumption that, within each layer during a given interval, equilibrium
conditions exist was liable to be incorrect if long time intervals and high airflow rates were used. To alleviate this situation, most of the equilibrium models were incorporated with thin layer drying and wetting equations.

Flood et al. (1972) first used the thin layer drying equations developed by Sabbath for this purpose. Morey et al. (1979a), on the other hand, modified Thompson's model (1972) by including Sabbath's thin layer drying equations along with the sorption and desorption equilibrium moisture equations of Thompson.

After using the modified model, they felt that the drying front progressed more slowly in the center of the bin than at other radial positions. Finally, they decided to use an airflow rate of 20-30% lower than the average experimental flow rate to cope with this inaccuracy.

Van Ee and Kline (1979b) found that the pure equilibrium model overpredicted the rate of both drying and wetting, especially in lower layers of the bin with high airflow rates. The Morey model without modification of the airflow rate was then employed in their management study of the corn drying for the central Iowa area.

In a study of the management of low temperature drying, Pierce and Thompson (1980b) modified Thompson's equilibrium model by incorporating a complete set of thin layer drying equations to cover a wide range of air temperatures. They suggested that the equilibrium model be used for airflow rates below 1.4 cfm/bu. For higher airflow rates, the drying equations were used for the following temperature ranges:

\[ T < 32^\circ F \]  Thompson's equilibrium model (Thompson, 1972)
0 - 70°F Sabbah equation
70 -110°F Misra-Brooker (1979)
110 -160°F Troeger-Hukill (1971)
160 -300°F Thompson et al. (1968)

However, no further validations of this arrangement were reported.

Mittal and Otten (1982) improved Morey's model by incorporating the thin layer equation from Misra and Brooker (1979) and a shrinkage model for the grain depth. They found that the optimum drying interval was 8 hours for a layer thickness of 0.29 to 0.32 in.

Management and Production Models

Purposes of management include reducing energy consumption and minimizing the system cost, reducing the drying time, maintaining good quality of grain, and matching the machinery selections with the crop production and harvest schedule.

Machinery Selection Models

Topics related to machinery selection can be found from several literature reviews (Hughes and Holtman, 1976; Edwards and Boehlje, 1980; Link and Bockhop, 1964; Russell and McHardy, 1970; Sorensen and Gilheany, 1970; Wolak et al., 1982; Singh and Holtman, 1979; Stapleton, 1967; Whitson et al., 1981; Ayres, 1973; Bonnicksen, 1967). Using a cost analysis technique, Liang (1971) developed an equipment selection approach to help a farmer determine the quantity of equipment or the optimal allocation of land for various crops which the farmer was
planning to grow.

On the other hand, Whitson et al. (1981) presented a procedure by including weather risk in maximizing the crop profit and optimizing machinery selections. A model was then developed to maximize returns to the fixed resources of a large scale farm. Results indicated that crop strategies and machinery selections should be mutually determined in profit maximizing models.

Production Models

Development of corn yield models has been attempted by several researchers (Childs et al., 1977; Corsi and Shaw, 1971; Curry, 1969; Curry and Chen, 1969; Duncan et al., 1967; Newman et al., 1968; Parsons and Holtman, 1976; Stapleton, 1970).

The Ohio soybean crop growth and development simulator (SOYM0D/OARDC) was used by Curry et al. (1975) and further investigated by Meyer et al. (1981) to predict dry matter and seed yield responses of soybeans. In this model, processes of flowering, podfill, and fruit absorption were considered.

A dynamic corn growth and development model (CORNF) was developed by Stapper and Arkin (1979) in simulating dry matter and yield of corn. Photoperiod-temperature-genotype interactions were taken into account.

Sudar et al. (1981) expanded a developed model (SPAW) which was previously used to estimate daily soil water evapotranspiration from readily available climate, crop and soil data. This model will estimate the crop water stress and determine the effect of the stress on canopy development, plant phenology and crop yield. They concluded that the
method was a practical and accurate approach for assessing the effects of water stress on crop yields.

Lorber and Haith (1981) developed a simple empirical model in conjunction with a soil moisture budget to estimate the effects of hybrid selection, planting date, moisture stress and frost on corn growth and yield. The input variables include daily temperature, precipitation and pan evaporation data. Comparison of model predictions with measured crop yields showed errors of 3-8%.

Harvesting and Drying

Many models have recently been advanced to study the corn harvesting and drying systems (Holtman et al., 1970; Carpenter and Brooker, 1970; Bridges et al., 1979a, b; Van Ee and Kline, 1979a, b; Spencer, 1969a, b, 1972). Most of these models considered field harvest date, weather condition, harvest rate, drying capacity and drying rate, and, in some instances, plant growth and related machinery selections. Morey et al. (1971a, b), Audsley and Boyce (1974), Philips and O'Callagham (1974), Loewer et al. (1980a, b), and Kambernik and Muir (1979) constructed models by combining the harvesting operation and a high temperature drying method.

Thompson (1972) demonstrated the effects of harvest date, initial moisture contents, grain temperatures and weather conditions on drying by a simulation using 1964-1969 weather data. Campbell and McQuitty (1971) constructed a model for an accepted harvesting system by incorporating the effects of weather, previous growing conditions and machine operations into the models for wheat. Three basic events were
included: grain maturation, grain threshing and grain storage. The computer output showed the number of days required for harvesting, the maturity date, no harvest days, total harvest acreage, total bushels harvested, quantities left unharvested and grain loss due to harvesting.

Morey et al. (1971b) used simulation techniques to analyze net profit of corn harvesting and handling systems during a particular weather year. Several factors such as the recoverable yield of grain, average moisture content on the field, weather probability, dryer capacity, and price of grain entered into the optimum policy model for decisions.

An extended study on a model including corn growth, harvesting, handling for a particular farm was conducted by Morey et al. (1971a). In this model, a 300-acre farm was provided as a basic unit with a combine having a capacity of 2.5 acres per hour. The model collected degree days for corn maturity from weather data and calculated the soil trafficability, grain dry-down on field, harvest loss and dryer capacity with user's inputs of planted acres, total heat units for corn varieties and expected maximum yield.

Computer output included average yield, average moisture content, variable drying cost, total annual net profits and many other data. Morey's model was further modified by Van Ee and Kline (1979a) by incorporating an automatic planting scheme and a built-in potential maximum yield to form the CORNSIM model. Data printed out from CORNSIM were then used as an input to the model FALDRY for a low temperature drying simulation.
Combination Drying Models

Combination drying, or high-low temperature drying, offers most of the advantages of low-temperature drying to the producer who often harvests corn at a high moisture content (Otten and Brown, 1982). In this method, wet corn is partially dried to 20-22% moisture content by a high temperature dryer and then is transferred to a low-temperature drying bin where it is slowly cooled and dried to a desired moisture content. The first stage is usually completed within two to twenty-four hours of harvest. The second stage of drying extends over a period of 4-8 weeks (Morey et al., 1981).

The performance of this arrangement has been tested by several researchers (Gustafson et al., 1976; Otten and Brown, 1982; Morey et al., 1976a, 1981). Potential advantages of this management include: (1) reducing energy required, (2) increasing drying system capacity, (3) improving grain quality (Morey et al., 1981).

Results of Otten and Brown's study (1982) indicated that the specific energy consumption varied between 1591 and 1763 Btu/lb of water removed. This appeared to be equal to that of a conventional high speed dryer but the grain quality such as viability, stress cracks and breakage potential was superior.

Kentucky Grain Handling Models

The University of Kentucky has developed a series of computer programs to assist farmers in making decisions on combine selections and grain storage facilities (Loewer et al., 1977). Four different models (CACHE, CHASE, BNDZN and SQUASH) have been suggested for this purpose to
handle different problems a farmer might encounter.

The CACHE model was used to determine the expected return of a shelled-corn farming operation with grain storage facilities as opposed to the same farming situation without grain storage (Loewer et al., 1977). Further study of CACHE was presented by Loewer et al. (1980a) to examine the influence of many factors such as harvesting strategies, facility management, market conditions, energy conditions and facility design on the economic return from on-the-farm grain storage facilities.

The program BNDZN was developed and employed to determine the purchase and annual costs of various types of centralized grain storage facilities, using cost analysis (Loewer et al., 1976a, b). In this model, layer bins, batch bins, and portable drying facilities were included.

It was found that purchase and annual costs decreased rapidly for capacities up to approximately 20,000 bushels and then tended to decrease at a lesser but more uniform rate. Layer drying systems had a slight purchase and annual cost advantage for capacities up to 10,000 bushels.

The model CHASE can examine or design a suitable harvesting, handling, drying and storage system for a farmer by ranking costs of a feasible system considered and by arranging the equipment and labor required by each feasible system (Bridges et al., 1979a). Extended applications of this model in determining the least cost drying method as a function of harvest date and drying time were conducted by Bridges et al. (1979b).
The SQUASH model simulated the activities of individual items of equipment, such as combines, vehicles and grain facilities (Loewer et al., 1977; Benock et al., 1981). In this model, grain was combined at a user-inserted rate and dumped into a delivery vehicle as the grain tank filled. Time and motion study was then examined on all vehicles and components of grain facilities.

Extended studies of a model HDHDSS on combine selections were presented by Loewer et al. (1980b) with information generated from the above two models (SQUASH and CHASE) to evaluate a designed machinery set over a range of daily harvesting capacities and to maximize the over-all system efficiency. On the average, the most important factor that influenced combine and delivery vehicle performances was the dryer capacity followed by a receiving conveyer, wet holding bin and dump pit.

Filling Strategies

Three kinds of filling strategies are in use today: single filling, layer filling and controlled filling.

Single Filling Most studies of low-temperature drying were focused on the single filling strategy because of its simple and fast loading (Morey et al., 1971a, b, 1976a, 1979a; Pierce and Thompson 1979, 1980a).

Pierce and Thompson (1979, 1980a) conducted a study to evaluate the effect of several management techniques on the performance of solar and low-temperature grain drying systems. A full bin drying was studied first with fall shut-down and spring re-starting procedures to complete drying of corn. A winter holding period for an intermittent aeration
was also employed. The fan was operated continuously until the grain moisture in the top layer was below 18%, to avoid an increase of dry matter decomposition (Pierce and Thompson, 1980a).

Mittal and Otten (1981) employed 12 different fan and heater management schemes for corn drying by using hourly weather data for 14 successive years. It was concluded that a continuous fan operation without supplemental heat was sufficient to dry grain in a favorable weather. None of the management schemes, however, was found to be energy efficient compared with high temperature drying for all years.

Layer Filling In a layer filling process, grain is added in layers at a preset time interval or by the time the drying front passes through the grain depth. Layer drying is a safe way to dry corn, but it can slow harvest when drying conditions are good. The operational factors affecting layer dryer performance are: (a) the ambient air conditions, (b) the initial moisture content of the grain and (c) the loading rate (Pierce and Thompson, 1980b).

Pierce and Thompson (1982) developed a drying scheduling model to provide the operator of low-temperature drying systems with needed management information for a layer-filling bin. The model was developed for use on the AGNET computer system. It utilized a drying simulation model, system setup information, minimum airflow requirements and projected field drydown rates to determine bin filling rates. Preliminary results showed that layer filling could typically be completed in a 2 to 3 week period with an efficient energy consumption of 300 Btu/lb of water removed.
On the basis of the Steele's (1963) criteria on grain deterioration and the total cost calculated by the simulation model, Morey and Peart (1971) determined the best combination of fan horsepower and grain depth for a natural air drying system. For layer filling of a 5,000 bu system, the optimum combination was approximately 5 horsepower and 12 feet in depth with 20 feet in diameter. They also examined both single-fill and layer-fill strategies with various loading intervals. Results showed that, as the loading interval became shorter, the optimum combination would shift to greater depths and lower power ratings.

To overcome the overdrying problems in layer drying, Pierce and Thompson (1980b) recommended several managements such as reversing airflow directions, recycling a portion of the exhaust air and stirring the grain as possible solutions.

In their model, appropriate thin layer drying equations were incorporated into the equilibrium model so that drying could be simulated for the relatively high air flow rates encountered in layer drying. The results showed that with a slower rate of loading, it was possible to handle higher moisture grain.

**Controlled Filling** Controlled filling is a method of managing layer filling by changing airflow rates. Therefore, the drying front does not come through the top before another layer is added (Midwest Plan Service, 1980). Filling proceeds as fast as drying conditions permit. Using this scheme, Van Ee and Kline (1979a, b) ran CORNSIM and FALDRY models for central Iowa conditions. They found, by using controlled filling, the bins could typically be filled in 2 to 3 weeks.
and successfully dried with about 1,000 hours of fan operation.

**Solar Energy Technique**

Another management technique to conserve energy for drying was the utilization of solar energy. Researches on solar grain drying were numerous (Kranzler et al., 1980; Pierce and Thompson, 1979; Morey et al., 1979b; Morrison and Shove, 1975; Rugumayo and Bakker-Arkema, 1978; Sabbah et al., 1979b; Bern et al., 1979, 1980). However, general conclusions of this management can be summarized as follows:

1. The requirements of purchased energy were generally lowest among managements not using solar energy (Pierce and Thompson, 1979).
2. The energy reduction for solar drying was not sufficient to pay for the cost of the collector (Bakker-Arkema et al., 1976; Pierce and Thompson, 1979; Kranzler et al., 1980; Anderson et al., 1980).
3. Supplemental solar heat generally reduced the minimum required airflow rate by 10-15% compared to ambient-air drying (Morey et al., 1979b).
4. Overdrying was more of a problem when supplemental heat was added.
5. Supplemental heat did not significantly reduce dry matter decomposition in the top layer of grain in most years (Morey et al., 1979b).

Different approaches on utilization of solar energy were developed by Anderson et al. (1980) to study overall drying system characteristics...
of the combination desiccant low temperature system for drying corn with solar heat, which was described by Bern et al. (1979, 1980). In this system, electrical energy and demand for combination system averaged 41 and 29% respectively of that required for the conventional system.
OBJECTIVES

1. Develop a FLDAY model that can predict the field workdays from local weather data for the CORNDRY model.
2. Develop a CORNDRY model by combining CORNSIM and FALDRY models which were developed earlier at Iowa State University.
3. Use the CORNDRY model to optimize corn growth, harvesting, drying and storage conditions for the northwestern Iowa area.
4. Develop an optimum daily filling strategy for a four-bin drying system using ambient air.
FUNCTIONS OF FLDAY AND CORNDRY MODELS

FLDAY and CORNDRY models are to be described in the following chapters. The FLDAY model will predict field workdays for the CORNDRY model for further studies.

The CORNDRY model is a combination of CORNSIM and FALDRY models. This new combined model will be used throughout our management studies. Both FLDAY and CORNDRY models use the same weather data base, but the FLDAY model will add the field workday in the data base as inputed to the CORNDRY model.
DEVELOPMENT OF THE FLDAY MODEL

Overview of the FLDAY Model

The purpose of the FLDAY model is to predict the daily field working condition from past weather records. The FLDAY model determines the day as a field workday by several parameters: the soil moisture in the top soil layers, precipitation, evapotranspiration, surface runoff, and air temperature.

Shaw (1963, 1965) developed two prediction models: one in a soil moisture budget under corn, the other in field workdays for spring in Iowa. These two models, however, were not related. In fact, Shaw's workday prediction model was not based on the soil moisture budget he developed. His soil moisture budget was later used for calculating the stress index (Corsi and Shaw, 1971; Morris, 1972), which, afterwards, became a means for the prediction of corn yield for Iowa (Shaw, 1977).

Modifications of Shaw's models are necessary if the prediction is going to cover a whole year range. The FLDAY model will be based on the soil moisture budget of Shaw (1963) and some criteria set up by Shaw (1965) and Hassan and Broughton (1975).

Data Collections

The Iowa Crop and Livestock Reporting Service has established a series of weekly reports on field workdays in Iowa since 1958. In this report, Iowa is divided into nine cropping districts, from which the available field workdays are summarized and reported in district
averages, accompanied by the state average.

A copy of the observed field workday records for the period 1960-1979 was obtained. The records were kept by calendar by week, including Saturday and Sunday. In this study, however, only the data of northwestern Iowa were used for a validation of the FLDAY model.

Climatological Data

For the northwestern Iowa area, complete weather data for this prediction model and for the revised CORNDRY model were not easily accessible. Therefore Sioux Falls, South Dakota, located near the corner of northwestern Iowa, was chosen as a reference location for this study. The weather observation data tape for Sioux Falls from 1960 to 1979 was provided by Climatic Center, USAF, Air Weather Service, NWRC, Office of Climatology, U. S. Weather Bureau. Data on this tape were recorded on a daily basis, with entries including the maximum, mean and minimum temperatures, relative humidity, precipitation, snow on the ground, and pan evaporation. All these data were sorted and re-arranged in a convenient format before inputed to the computer program.

Soil Moisture Budget

To simplify the algorithm of the model, a soil profile of only 12 in. was considered and was divided into two principal zones with each zone 6 in. in depth. Water in the top 6 in. layer becomes a pre-indicator of the soil tractability for farm equipment and machinery. The second 6 in. layer, however, acts merely as a water basin for
receiving water drained from the top layer.

To reflect the actual water activity occurring during that day on the surface, the top 1 in. layer was isolated from the upper layer and was treated separately as a temporary water storage. After any possible events were over, the actual water activities then continued to penetrate through the whole upper layer.

Figure 2 shows details of the soil profile and the possible water movements that might inflow and outflow from the model. Factors under consideration include precipitation, surface runoff, evaporation, diffusion and drainage between layers and evapotranspiration (ET) from the plant body.

Precipitation becomes the main source of water that flows into the model, or, to the surface layer. The received water then evaporates, runs off or will be stored in the upper layer. As time goes on, the water might drain to or diffuse from the lower zone, where water might drain away beyond the lower layer or be absorbed by roots of the plant. The whole moisture budget can be expressed in the following equations:

For the surface layer:

$$SM1(i) = SM1(i-1) + Pt_i - RUNOFF(i) - EVP(i) + DIFF(i)$$

For the upper layer:

$$SM2(i) = SM2(i-1) + Pt_i - RUNOFF(i) - EVP(i) + DIFF(i) - DRAIN(i)$$

For the lower layer:

$$SM3(i) = SM3(i-1) - DIFF(i) - ROOT(i) + DRAIN(i)$$
FIGURE 2. A soil profile for the water movements
where

\[ \text{RUNOFF} = \text{water runoff from the surface, in.} \]
\[ \text{EVP} = \text{evaporation from the surface, in.} \]
\[ \text{Pt} = \text{precipitation, in.} \]
\[ \text{SM1,SM2,SM3} = \text{soil moisture in each layer, in.} \]
\[ \text{DIFF} = \text{water diffusion between layers, in.} \]
\[ \text{ROOT} = \text{water absorbed by plant roots and transpired, in.} \]
\[ \text{DRAIN} = \text{water drained from upper layer to lower layer, in.} \]
\[ i = \text{today's date.} \]

Moistures of both layers in the top 6 in. soil will be used as the basic terms in judging the feasibility of field workdays.

Field Capacity

The field capacity of soil is related to soil types. According to Shaw's report (1963), the field capacity of most Iowa soil can be 2.5 in. in the top 12 in. layer. Accordingly, 1.25 in. was assigned for each zone and 0.21 in. for the surface layer in this model. All available moistures in the final judgement were based on the percentage of field capacity.

For the first-year run, the soil available moisture was made equal to the saturated condition or equal to the field capacity in the very beginning. Afterwards, moisture at end of the last year then became that at the beginning of the next year.
Runoff and Drainage

Surface runoff was computed as a function of the current and past precipitation records with a small correction for periods of the spring and fall. To estimate surface runoff, Shaw (1963, 1965) used an indicator called an antecedent precipitation index (API), as expressed as follows:

\[ API = P_0 + P_1 /1 + P_2 /2 + \ldots + P_i /i \]

where \( P_0 = 0 \) when precipitation (Pt) ≤ 1 in.,
or after Aug. 31.

\( P_0 = Pt/2 \) when precipitation (Pt) > 1 in.

\( i = \) days prior to the day being considered.

On subsequent days, \( P_0 \) was carried in the expression of \( P_1 \).

Figure 3 shows the relationship between runoff and API index.

The amount of rain that does not run off is then added to the surface layer where the excess moisture, if any, over field capacity will be drained to the second layer, depending on the preset drainage coefficient (DRS). Dyer and Baier (1979) used a drainage coefficient of 0.7-0.8 in their study, while Elliott et al. (1977) applied a drainage rate of 1 in./day to their model. Obviously, the drainage rate or drainage coefficient is very dependent on types and locations of soil and, therefore, its exact value for a specific location is not usually available. In our study, however, a drainage coefficient of 0.9 was used for the Iowa soil condition. The drainage (DRAIN) can be expressed
FIGURE 3. Revised relationship for API, runoff and precipitation (from Shaw, 1963, 1965)

as:

\[ \text{DRAIN}_{1-2} = (\text{SM}_1 - \text{FC}_1) \times \text{DRS} \]

\[ \text{DRAIN}_{2-3} = (\text{SM}_2 - \text{FC}_2) \times \text{DRS} \]

where \( \text{FC}_1, \text{FC}_2 = \) field capacity of the top layers, in.

\( \text{DRS} = \) drainage per day.

\( \text{DRAIN} = \) drainage, in/day.
1,2,3 = layer numbers.

Drainage occurs among the three zones and the zone below the lower one. However, any drainage that occurs below the lower zone is ignored.

Diffusion among layers, although it is small, is also considered in the model. Dyer and Baier (1979) took a coefficient of 0.2 per day for this term in their report. For convenience, this value is also used for the Iowa soil condition in this study. The water transfer due to diffusion (DIFF) then can be calculated as follows:

\[
\text{DIFF}^{(2-1)} = (\frac{SM_2}{FC_2} - \frac{SM_1}{FC_1}) \times FC_1 \times DUP
\]
\[
\text{DIFF}^{(3-2)} = (\frac{SM_3}{FC_3} - \frac{SM_2}{FC_2}) \times FC_2 \times DUP
\]

in which
- DIFF = diffusion rate, in./day.
- DUP = diffusion coefficient, per day.
- FC3 = field capacity of the lower layer, in.
- 1,2,3 = layer numbers.

Evapotranspiration

In most models, the procedure employed in predicting the water vapor loss depends on the time of season and the stage of crop development. Sometimes, a stress factor is also included. Shaw (1963) concluded from his moisture budget that use of pan evaporation as the data base usually gave reasonable results in the soil moisture prediction. Therefore, with pan evaporation given, the potential ET can be adjusted by the growing stage of corn as shown in Figure 4.
Since only two upper layers will be considered in our model, this 12 in. soil profile, according to Shaw's vapor distraction table, will then only contribute 60% of the total ET.

![Diagram](attachment:image.png)

**FIGURE 4.** Ratio of evapotranspiration (ET) of corn to open-pan evaporation throughout the growing season (Shaw, 1963)

The new distribution of soil moisture in the whole profile is arranged in a way that the evaporation takes place directly from the surface or the upper layer and the transpiration from the plant is withdrawn from the rooting area, or, mostly from lower layers. Therefore, we assume that 30% of the total ET calculated from Figure 4 is extracted from the lower layer, starting from June 7 to oct. 1. For
the loss due to surface evaporation, several combinations in terms of ratios of the open pan evaporation were examined in this study to find an optimum one. Results showed that, for northwestern Iowa, the appropriate loss due to surface evaporation was 40% of open pan evaporation before June 7 and 30% thereafter.

Shaw (1963) also imposed a moisture stress factor on the actual ET when the soil moisture came close to being depleted. Figure 5 shows two curves of ET ratio during periods before and after August 1. Three levels of stress status are also shown on these two curves, in which days when pan evaporation is above 0.3 in. are classified as high-stress days, below 0.2 in. as low-stress days, and between 0.2 and 0.3 in. as average-stress days. Stress factor can be computed in the model by a subroutine program ETS.

Pan evaporation was as a good indicator of moisture changes in the soil profile but, unfortunately, missing data were common for some years or for a certain time in a year. To make up this shortcoming, a subroutine ESPAN was developed to provide these data when they were missing. Equations listed below are the basic algorithm of the ESPAN subroutine, in which the factors were determined empirically from the existing weather data of some years:

At an average temperature of 50°F,

\[
\begin{align*}
\text{RH} \leq 40\% & \quad \text{PAN} = 0.45 \text{ in.} \\
40\% < \text{RH} \leq 50\% & \quad \text{PAN} = 0.40 \text{ in.} \\
50\% < \text{RH} \leq 60\% & \quad \text{PAN} = 0.30 \text{ in.}
\end{align*}
\]
FIGURE 5. Relative evapotranspiration rate for atmospheric demand rate. ET is actual evapotranspiration. ETO is open-pan evaporation (Shaw, 1963 and 1965)
60% < RH ≤ 70%  PAN = 0.20 in.
70% < RH ≤ 80%  PAN = 0.10 in.
80% < RH ≤ 100% PAN = 0.05 in.

Temperature other than 50 °F, a correction factor, f, is assumed:

\[ f = 1 + (T_{av} - 50) \times 0.005 \]

ESPAN = f * PAN

in which  RH = relative humidity, %.

\( T_{av} \) = average temperature, °F.

PAN = pan evaporation, in.

ESPAN = estimated pan evaporation, in.

Special Physical Conditions of Soil

At the beginning and during the end period of each year, soil conditions of the previous day will be examined if the soil is going to be frozen or thawed. Several conditions described by Shaw (1965) are used for this purpose, as briefly described below:

1. The soil was considered frozen when (a) the maximum air temperature was less than 32 °F for at least 2 consecutive days, or (b) the minimum air temperature was less than 22 °F, or (c) any measurable snow was present on the ground for at least 2 consecutive days, regardless of air temperature, or, (d) a minimum air temperature of less than 20°F was recorded.
2. The soil was thawing when (a) the minimum temperature was greater than 32°F for 2 consecutive days, or, (b) the maximum temperature was greater or equal to 70°F, or, (c) maximum temperature was greater than 60°F and minimum temperature greater than 32°F, or, (d) air temperature was greater than or equal to 50°F and precipitation was greater than 0.5 in., or, (e) the minimum air temperature was greater or equal to 32°F and precipitation was greater than 0.5 in.

3. Passing to step (1) or step (2) is determined by the soil condition of the previous day (see Figure 6)

4. If the soil cannot pass step (1) above, a thawing condition is then assumed and soil moisture needs to be adjusted for the thawing snow on the ground, if any.

5. If soil begins freezing from step (2), the soil moisture will remain unchanged and additional precipitation, if any, will be saved in the form of snow on the ground.

The freezing-thawing process could occur both in spring and fall and could be repeated several times in one season also. During the fall, however, frozen soil might still be considered as a tractable condition for combines to harvest the last grain in the field on a day without precipitation.

Criteria of Field Workdays

Factors that affect the possibility of field workdays include soil moisture, rainfall, and snowing condition on the past few days.
FIGURE 6. The flowchart for the main program in predicting field workdays
and Broughton (1975) designed some criteria, on the basis of soil moisture on the top layers, to classify field workdays as shown in Table 1.

TABLE 1. Tractability criteria for different soils (Hassan and Broughton, 1975)

<table>
<thead>
<tr>
<th>soil type</th>
<th>depth</th>
<th>%field capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay 1 (AW1)</td>
<td>0-1&quot;</td>
<td>66</td>
</tr>
<tr>
<td>clay 2 (AW2)</td>
<td>0-6&quot;</td>
<td>99</td>
</tr>
<tr>
<td>clay loam 1 (AW1)</td>
<td>0-1&quot;</td>
<td>60</td>
</tr>
<tr>
<td>clay loam 2 (AW2)</td>
<td>0-6&quot;</td>
<td>95</td>
</tr>
<tr>
<td>sandy loam 1 (AW1)</td>
<td>0-1&quot;</td>
<td>70</td>
</tr>
<tr>
<td>sandy loam 2 (AW2)</td>
<td>0-6&quot;</td>
<td>98.5</td>
</tr>
</tbody>
</table>

*Symbols that appear in Figure 7.*

Based on the tractability criteria stated in Table 1, some rules for the field workday decision can be outlined as follows (for clay loam):

1. If the moistures of the surface and upper layer are both below the criteria, one full workday is assumed.
2. If either layer fails to meet the criteria, no workday is assumed except that half a workday will be considered if the moisture of that particular layer is still below 100%.
3. On a raining day, if the previous day is a good field workday, and today's precipitation is higher than 0.2 in., it is then assumed to be a half day, which, might become a full
workday later after passing through a decision process.

4. For the consecutive raining days, the criteria for the field workday will be the same as that for a clear day but, because of existing precipitation, only a half workday can be assumed if it passes through the test of step (1).

5. All the half workdays have to pass through a decision procedure to force them from becoming a full or a non-field workday by chance.

Figure 7 shows the flowchart of whole field workday decision procedures.

Function Subroutines

The FLDAY model contains six main subroutines, of which the interconnection can be shown in Figure 8. First of all, the main program manages the weather data input, checks the missing data of pan evaporation and calls the ESPAN subroutine to estimate if necessary.

Also, it calls FLDAY to determine the field working condition, and calls PRNTS to print out the necessary report forms. Detailed functions of each subroutine can be summarized as follows:

FLDAY--The FLDAY subroutine is the main subroutine which handles the whole field workday decision procedures as shown in a flowchart in Figure 6. As weather data are sent in, FLDAY checks the soil physical conditions as to whether it is in a thawing or frozen condition first and then proceeds through RUN to calculate the amount of runoff, through ETO and ETS to calculate the actual evaporation and then through WKDY to determine the field working
FIGURE 7. The flowchart of whole field workday decision procedures

LABELS
AW1, AW2: See Table 1.
NR: No. of raining days.
RAIN: Rainfall, in.
WD: Field work condition.
SM1, SM2: Soil moisture in upper layers.

NL = 0
NR = 0
RAIN = 0
NR = NR + 1
RAIN > 0.2
WD = 0.5
NR ≥ 3 AND RAIN > 0.05
NR = 2 AND RAIN > 0.1
SM1 > AW1
SM2 > AW2
SM1 > 1.0
SM2 > 1.0
WD = 1
WD = 0
WD = 0.5
RETURN
ADJUSTMENT OF FIELD WORKDAY
FIGURE 8. The interconnection between subroutines in the FLDAY model

condition. The moistures of the soil profile are evaluated in this subroutine by layers. The soil moisture changes due to drainage and diffusion, however, are adjusted at end of that day.

RUN--The amount of runoff after rain is calculated by using the API index, which, as described earlier, counts the past records of precipitation for seven days. The return value of this function is the amount of moisture difference between precipitation and the runoff that day.
ETS--This is a function subroutine which calculates the stress factor of soil at different stages. Curves as shown in Figure 5 have been replaced by several equations in the model.

ETO--The main function of ETO is to compute the ratio of potential ET and open pan evaporation, corresponding to the Julian date—a curve as shown in Figure 4.

ESPAN--This is a function subroutine which estimates the open pan evaporation by using air temperature and relative humidity. Data evaluated by this subroutine are on a daily basis.

WKDY--Based on the soil moistures SM1, SM2, and raining condition, the WKDY subroutine determines the field working condition of that day. Three kinds of soil—clay, clay loam and sandy loam—are built in this model. The decision procedure has been shown as in Figure 7.
VALIDATION OF THE FLDAY MODEL

The FLDAY model was validated by using observed data of field workdays from the Iowa Crop and Livestock Reporting Service (1960-1979). Because the observed field workdays were reported on a weekly basis, the data generated from FLDAY were then collected by the same periods as the Iowa Crop and Livestock Reporting Service did. An example output is shown as in Appendix B, in which the precipitation and the field workday schedule are included.

The observed field workdays from the report usually start in April and end in October, leaving data of other periods unaccessible. Although, as we know, most of these periods, especially in the early spring, are not workable in the field, data of these periods are still of importance to the validation of FLDAY model. To explain these missing data, two assumptions were made for data correction before a regression analysis was run. First, if the outcome of field workdays within a specific week from a model prediction was zero and, during the same week, the observed data were missing, the observed data of that week were then assumed zero; second, during harvest time, if the predicted data were a full seven days that week but observed data were missing, then the observed data of that week were assumed 7 days that week. The reasons for these assumptions are based on the fact that, during the period from January to April, non-workable days are likely to result and, therefore, confidence of the predictions from the model increases if there is no field workday predicted in that week. Comparisons for both corrected and uncorrected data in regression
analysis are shown in Tables 2 and 3.

From Table 2, the correlation coefficients from 1960 to 1979 range from 0.41 to 0.91 with an overall coefficient of 0.714. The years of low coefficient mostly have their data points clustered in a high value region with few or none of points passing through the origin. Therefore, the correlation and regression lines fail to represent the actual case properly. Typical examples of these years are 1969 and 1976.

Table 3 shows the regression equations and correlation coefficients for both individual years and cumulative years from 1960 to 1979. Most years under these adjustments have correlation coefficients higher than 0.90, including those years that have lower coefficients before adjustments. The overall correlation coefficient reaches 0.923 in this case.

Figure 9 shows the relationship of collected and predicted data points for 1960 and 1962. Both results appear to be normal but for the weekly periods of low field workdays the model tends to underestimate the data in 1962 and tends to overpredict the weekly field workdays in 1960.

Figure 10 shows the relationship of the predicted and observed field workdays of years 1976 and 1978. Both are extreme cases. In 1976, the coefficient of correlation was as low as 0.41 (Table 2) but, judging by the distribution of data points in Figure 10a, the reason for improvements in correlation coefficients after adjustments becomes obvious. Most data points fall in the upper right region. The year
TABLE 2. Regression analysis of field workday predictions (uncorrected)

<table>
<thead>
<tr>
<th>Year</th>
<th>Equations</th>
<th>Correlation</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>$Y = (1.607097) + (0.713723)X^a$</td>
<td>RR= 0.649375</td>
<td>35</td>
</tr>
<tr>
<td>1961</td>
<td>$Y = (2.228304) + (0.665753)X^a$</td>
<td>RR= 0.593361</td>
<td>37</td>
</tr>
<tr>
<td>1961^b</td>
<td>$Y = (-3.700586) + (1.574670)X^a$</td>
<td>RR= 0.882595</td>
<td>29</td>
</tr>
<tr>
<td>1962</td>
<td>$Y = (0.670676) + (0.881863)X^a$</td>
<td>RR= 0.670832</td>
<td>101</td>
</tr>
<tr>
<td>1962^b</td>
<td>$Y = (1.911133) + (0.691945)X^a$</td>
<td>RR= 0.620116</td>
<td>33</td>
</tr>
<tr>
<td>1963</td>
<td>$Y = (1.437134) + (0.812241)X^a$</td>
<td>RR= 0.655011</td>
<td>72</td>
</tr>
<tr>
<td>1963^b</td>
<td>$Y = (0.688564) + (0.894576)X^a$</td>
<td>RR= 0.679388</td>
<td>134</td>
</tr>
<tr>
<td>1964</td>
<td>$Y = (1.156720) + (0.844977)X^a$</td>
<td>RR= 0.716204</td>
<td>33</td>
</tr>
<tr>
<td>1964^b</td>
<td>$Y = (0.799714) + (0.881528)X^a$</td>
<td>RR= 0.684999</td>
<td>167</td>
</tr>
<tr>
<td>1965</td>
<td>$Y = (2.288611) + (0.684224)X^a$</td>
<td>RR= 0.816047</td>
<td>33</td>
</tr>
<tr>
<td>1965^b</td>
<td>$Y = (1.313233) + (0.802483)X^a$</td>
<td>RR= 0.694216</td>
<td>200</td>
</tr>
<tr>
<td>1966</td>
<td>$Y = (1.387134) + (0.812084)X^a$</td>
<td>RR= 0.620833</td>
<td>34</td>
</tr>
<tr>
<td>1966^b</td>
<td>$Y = (3.776184) + (0.440122)X^a$</td>
<td>RR= 0.687626</td>
<td>234</td>
</tr>
<tr>
<td>1967</td>
<td>$Y = (1.729683) + (0.964490)X^a$</td>
<td>RR= 0.572061</td>
<td>37</td>
</tr>
<tr>
<td>1967^b</td>
<td>$Y = (1.319019) + (0.863247)X^a$</td>
<td>RR= 0.783868</td>
<td>37</td>
</tr>
<tr>
<td>1968</td>
<td>$Y = (1.700209) + (0.754953)X^a$</td>
<td>RR= 0.684979</td>
<td>308</td>
</tr>
<tr>
<td>1969</td>
<td>$Y = (4.880258) + (0.255809)X^a$</td>
<td>RR= 0.438364</td>
<td>34</td>
</tr>
<tr>
<td>1969^b</td>
<td>$Y = (2.082253) + (0.694119)X^a$</td>
<td>RR= 0.655550</td>
<td>342</td>
</tr>
<tr>
<td>1970</td>
<td>$Y = (-0.372221) + (1.067577)X^a$</td>
<td>RR= 0.779564</td>
<td>34</td>
</tr>
<tr>
<td>1970^b</td>
<td>$Y = (1.711018) + (0.752391)X^a$</td>
<td>RR= 0.676378</td>
<td>376</td>
</tr>
<tr>
<td>1971</td>
<td>$Y = (0.567738) + (0.962189)X^a$</td>
<td>RR= 0.787440</td>
<td>31</td>
</tr>
<tr>
<td>1971^b</td>
<td>$Y = (1.645260) + (0.764942)X^a$</td>
<td>RR= 0.683665</td>
<td>407</td>
</tr>
<tr>
<td>1973</td>
<td>$Y = (2.224358) + (0.672412)X^a$</td>
<td>RR= 0.680958</td>
<td>33</td>
</tr>
<tr>
<td>1973^b</td>
<td>$Y = (1.690866) + (0.757720)X^a$</td>
<td>RR= 0.682992</td>
<td>440</td>
</tr>
<tr>
<td>1974</td>
<td>$Y = (1.005022) + (0.880670)X^a$</td>
<td>RR= 0.789386</td>
<td>35</td>
</tr>
<tr>
<td>1974^b</td>
<td>$Y = (1.649434) + (0.765270)X^a$</td>
<td>RR= 0.689662</td>
<td>475</td>
</tr>
<tr>
<td>1975</td>
<td>$Y = (1.140735) + (0.824465)X^a$</td>
<td>RR= 0.770267</td>
<td>33</td>
</tr>
<tr>
<td>1975^b</td>
<td>$Y = (1.584496) + (0.774869)X^a$</td>
<td>RR= 0.700920</td>
<td>508</td>
</tr>
<tr>
<td>1976</td>
<td>$Y = (3.435375) + (0.484770)X^a$</td>
<td>RR= 0.410461</td>
<td>33</td>
</tr>
<tr>
<td>1976^b</td>
<td>$Y = (1.618133) + (0.769540)X^a$</td>
<td>RR= 0.696812</td>
<td>541</td>
</tr>
<tr>
<td>1977</td>
<td>$Y = (1.773726) + (0.728110)X^a$</td>
<td>RR= 0.643979</td>
<td>35</td>
</tr>
<tr>
<td>1977^b</td>
<td>$Y = (1.624009) + (0.767994)X^a$</td>
<td>RR= 0.696159</td>
<td>576</td>
</tr>
<tr>
<td>1978</td>
<td>$Y = (0.543075) + (0.954105)X^a$</td>
<td>RR= 0.906106</td>
<td>32</td>
</tr>
<tr>
<td>1978^b</td>
<td>$Y = (1.557833) + (0.779316)X^a$</td>
<td>RR= 0.708145</td>
<td>608</td>
</tr>
<tr>
<td>1979</td>
<td>$Y = (1.594012) + (0.751404)X^a$</td>
<td>RR= 0.746212</td>
<td>34</td>
</tr>
<tr>
<td>1979^b</td>
<td>$Y = (1.556554) + (0.778658)X^a$</td>
<td>RR= 0.713928</td>
<td>642</td>
</tr>
</tbody>
</table>

aX, Y= Observed and predicted field workdays per week.
Cumulative regression figures from 1960 to that year.
TABLE 3. Regression analysis of field workday predictions (corrected for zero)

<table>
<thead>
<tr>
<th>Year</th>
<th>Equations</th>
<th>Correlation</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>$Y = (0.281535) + (0.942412)X^a$</td>
<td>$RR = 0.911604$</td>
<td>49</td>
</tr>
<tr>
<td>1961</td>
<td>$Y = (0.446642) + (0.979021)X$</td>
<td>$RR = 0.895844$</td>
<td>46</td>
</tr>
<tr>
<td>1961b</td>
<td>$Y = (0.357196) + (0.961905)X$</td>
<td>$RR = 0.903807$</td>
<td>95</td>
</tr>
<tr>
<td>1962</td>
<td>$Y = (-0.479636) + (1.023417)X$</td>
<td>$RR = 0.926022$</td>
<td>41</td>
</tr>
<tr>
<td>1962b</td>
<td>$Y = (0.112560) + (0.978948)X$</td>
<td>$RR = 0.906403$</td>
<td>136</td>
</tr>
<tr>
<td>1963</td>
<td>$Y = (0.177219) + (1.017368)X$</td>
<td>$RR = 0.951865$</td>
<td>41</td>
</tr>
<tr>
<td>1963b</td>
<td>$Y = (0.112756) + (0.992882)X$</td>
<td>$RR = 0.916586$</td>
<td>177</td>
</tr>
<tr>
<td>1964</td>
<td>$Y = (0.605181) + (0.939157)X$</td>
<td>$RR = 0.838863$</td>
<td>36</td>
</tr>
<tr>
<td>1964b</td>
<td>$Y = (0.155993) + (0.991383)X$</td>
<td>$RR = 0.909872$</td>
<td>213</td>
</tr>
<tr>
<td>1965</td>
<td>$Y = (0.672728) + (0.971250)X$</td>
<td>$RR = 0.930941$</td>
<td>44</td>
</tr>
<tr>
<td>1965b</td>
<td>$Y = (0.287918) + (0.978605)X$</td>
<td>$RR = 0.912107$</td>
<td>257</td>
</tr>
<tr>
<td>1966</td>
<td>$Y = (0.410759) + (1.008329)X$</td>
<td>$RR = 0.921489$</td>
<td>43</td>
</tr>
<tr>
<td>1966b</td>
<td>$Y = (0.300228) + (0.984441)X$</td>
<td>$RR = 0.913333$</td>
<td>300</td>
</tr>
<tr>
<td>1967</td>
<td>$Y = (1.047140) + (0.891639)X$</td>
<td>$RR = 0.900995$</td>
<td>43</td>
</tr>
<tr>
<td>1967b</td>
<td>$Y = (0.386934) + (0.992882)X$</td>
<td>$RR = 0.911133$</td>
<td>343</td>
</tr>
<tr>
<td>1968</td>
<td>$Y = (0.358801) + (1.030605)X$</td>
<td>$RR = 0.935666$</td>
<td>44</td>
</tr>
<tr>
<td>1968b</td>
<td>$Y = (0.388024) + (0.979571)X$</td>
<td>$RR = 0.913126$</td>
<td>387</td>
</tr>
<tr>
<td>1969</td>
<td>$Y = (0.906074) + (1.008329)X$</td>
<td>$RR = 0.894574$</td>
<td>47</td>
</tr>
<tr>
<td>1969b</td>
<td>$Y = (0.462008) + (0.971964)X$</td>
<td>$RR = 0.909805$</td>
<td>434</td>
</tr>
<tr>
<td>1970</td>
<td>$Y = (-0.086715) + (1.008329)X$</td>
<td>$RR = 0.905787$</td>
<td>47</td>
</tr>
<tr>
<td>1970b</td>
<td>$Y = (0.385059) + (0.984441)X$</td>
<td>$RR = 0.909876$</td>
<td>481</td>
</tr>
<tr>
<td>1971</td>
<td>$Y = (0.071518) + (1.047099)X$</td>
<td>$RR = 0.957977$</td>
<td>42</td>
</tr>
<tr>
<td>1971b</td>
<td>$Y = (0.355215) + (0.986886)X$</td>
<td>$RR = 0.914329$</td>
<td>523</td>
</tr>
<tr>
<td>1972</td>
<td>$Y = (0.467210) + (0.980655)X$</td>
<td>$RR = 0.922725$</td>
<td>43</td>
</tr>
<tr>
<td>1972b</td>
<td>$Y = (0.348145) + (0.987168)X$</td>
<td>$RR = 0.920133$</td>
<td>566</td>
</tr>
<tr>
<td>1973</td>
<td>$Y = (0.298947) + (0.999875)X$</td>
<td>$RR = 0.931844$</td>
<td>42</td>
</tr>
<tr>
<td>1973b</td>
<td>$Y = (0.345978) + (0.987779)X$</td>
<td>$RR = 0.920930$</td>
<td>608</td>
</tr>
<tr>
<td>1974</td>
<td>$Y = (0.303336) + (0.964846)X$</td>
<td>$RR = 0.911397$</td>
<td>47</td>
</tr>
<tr>
<td>1975</td>
<td>$Y = (0.341943) + (0.986728)X$</td>
<td>$RR = 0.920674$</td>
<td>655</td>
</tr>
<tr>
<td>1975b</td>
<td>$Y = (0.302211) + (0.983376)X$</td>
<td>$RR = 0.931510$</td>
<td>44</td>
</tr>
<tr>
<td>1976</td>
<td>$Y = (0.3040912) + (0.986174)X$</td>
<td>$RR = 0.921555$</td>
<td>699</td>
</tr>
<tr>
<td>1977</td>
<td>$Y = (0.574994) + (0.961903)X$</td>
<td>$RR = 0.861246$</td>
<td>41</td>
</tr>
<tr>
<td>1977b</td>
<td>$Y = (0.353608) + (0.984936)X$</td>
<td>$RR = 0.919195$</td>
<td>740</td>
</tr>
<tr>
<td>1978</td>
<td>$Y = (0.112544) + (1.027242)X$</td>
<td>$RR = 0.975541$</td>
<td>44</td>
</tr>
<tr>
<td>1978b</td>
<td>$Y = (0.337953) + (0.987635)X$</td>
<td>$RR = 0.922534$</td>
<td>788</td>
</tr>
<tr>
<td>1979</td>
<td>$Y = (0.452232) + (0.961671)X$</td>
<td>$RR = 0.915034$</td>
<td>50</td>
</tr>
<tr>
<td>1979b</td>
<td>$Y = (0.346794) + (0.985884)X$</td>
<td>$RR = 0.922426$</td>
<td>828</td>
</tr>
</tbody>
</table>

$^a$ $Y$, $X$: Observed and predicted field workdays per week.

$^b$ Cumulative regression figures from 1960 to that year.
1978 is the best case of predictions from the model, however. The correlation of this year reaches 0.906 even before being adjusted.

Figure 11 gives a whole picture of data distributions from 1960 to 1969. A particular note for this graph is that some points may represent several observations which do not show.

Some of the following reasons might be the causes of sources of errors in the validation procedure:

1. The observed data are only the average of those 9 counties in northwestern Iowa. Discrepancies are expected because the model only uses weather of one specific location to predict the results.

2. The average observed field workdays are expressed in a decimal form. The predicted values, however, are in an integer form.

3. Missing data exist every year.

In all, according to the results we discussed, the FLDAY model can predict field workdays satisfactorily for northwestern Iowa from weather data of Sioux Falls. These data will be used as an input of the CORNDRY model for a further study of a corn production and drying system for the same area.
FIGURE 9. Relationship of predicted and observed workdays per week for 1960 and 1962
FIGURE 10. Relationship of predicted and observed workdays per week for 1976 and 1978
Regression: \( Y = 0.3468 + 0.9859X \) \( R = 0.9224 \)

**Figure 11.** Relationship of predicted and observed workdays per week for years 1960-1979.
DEVELOPMENT OF THE CORNDRY MODEL

Overview of the CORNDRY Model

The CORNDRY model is a combination of two deterministic models—CORN Simmons and FALDRY which were developed by Van Ee and Kline (1979a, b) at Iowa State University. The model can be used to define possible outcomes of management of corn production operating during the past 20 years for a farm of 300 acres with a combine and drying facilities of one to six bins as parts of the whole system for northwestern Iowa. CORNSIM is a sequential model which simulates several farming events of corn growth within a year until corn is harvested. Thereafter, the FALDRY model takes over the drying operations for the rest of year and, if necessary, extends its drying operation until the spring of the following year.

CORN Simmons and FALDRY are not run on the same weather data base at the same time, although the latter takes the harvested data directly from the former one. Combining these two models becomes necessary, especially when the controlled filling strategy is to be exercised. CORNDRY was developed not only to combine these two models, but also to update the content of the drying model and the whole program technique. In the new CORNDRY model, the user will find that data input is more flexible and use of this model will not be so restrictive to a certain area as before.

CORNDRY works on a 24-h weather data base. It can also be applied for any time interval when it is switched to the FALDRY mode for grain
drying purposes.

Figure 12 shows all farming events that might occur within a year. The model starts from April 1 by counting the field workdays which were previously generated from the FLDAY model. The first 10 or 15 good days from April 1 are reserved by the user for spring tillage and soil preparation. After that, the planting operation starts at a user's specified planting rate.

After corn is planted in an assigned field plot, a corresponding growing degree unit will then be accumulated and checked by its preset criteria from weather data until the corn of that plot enters the silking stage. A period from silking to dent stage will be examined by counting a certain number of calendar days. The ear corn develops and finally reaches a dry-down stage when moisture of the corn is about 75%. At this stage, a field dry-down schedule for corn will be applied, and the kernel moisture decreases from 75% to about 30%, at which time the corn is mature.

Harvest starts at end of this dry-down period as long as the field trafficability, corn moisture and the system drying capacity meet the preset requirements. As soon as corn is harvested, the second part of CORNDRY (the original FALDRY model) is called to distribute harvested corn into proper bins and drying operations begin.

Just like FALDRY, CORNDRY is a low-temperature grain drying model designed to simulate a system of one to six drying bins with perforated floors and axial-flow fans. Bin capacity and fan size can be varied individually according to the user's own specifications.
FIGURE 12. Farming operations occurring within a year for the CORNDRY model
Simulation begins on the date the harvested grain is loaded and continues drying operations until the corn in bins is completely dry. A shutdown schedule is provided in the CORNDRY model to stop drying operations in fall when complete drying within that year becomes impossible. The whole operation will be restarted after April 1 of the following year. A simple fall shutdown schedule for a fan is described in Figure 13. Spring shutdown by May 20 must be accomplished for loadings of previous year regardless of grain drying conditions.

The CORNDRY model contains many unique aspects:

1. The harvesting operation is directly combined with the grain distribution system and drying operation without any interruption in a run. Nevertheless, the model itself still maintains the original functions of CORNSIM and FALDRY models and can be run separately without interference.

2. New modification of Thompson's model is made to take the place of Sabbah's equation used in Morey et al. (1979a) and Van Ee's models (1979).

3. The grain shrinkage during the drying period is considered. Therefore, 7%-10% shrinkage of grain depth is expected.

4. Energy consumption for water evaporation is calculated accordingly and can be compared with other types of loading.

5. Thompson's (1972) aeration model is also built into the program to simulate the possibility of aeration during the winter holding period.

6. During drying and aeration periods, humidistat and thermostat
Fan Management Strategy for CORNDRY Model

1. The fan starts as soon as the first bushel of corn enters the bin and runs continuously until the user specifies he has finished filling the bin, at which time the fall and final shutdown logic takes control. If final shutdown conditions are met before the user indicates that filling is complete, the fan temporarily shuts down until more corn enters the bin.

2. Final shutdown of the fan occurs as soon as average corn moisture is less than 14.5% and maximum corn moisture in a layer is less than 15.5%, or as the date reaches May 20 for the following year.

3. If conditions for final shutdown do not occur during the fall drying season, the fall shutdown criteria will turn off the fan and restart it on April 1. Fall shutdown occurs when any one of four conditions are met:
   a. The date is after November 15, and the top layer of grain is less than 30°F and less than 18%.
   b. The date is after December 1 and the top layer of grain is less than 25°F and less than 20%.
   c. The date is after December 1 and the top layer of grain is less than 20°F.
   d. The date is December 16.

Winter dry matter deterioration is predicted, based on fall shutdown conditions. The effects of winter operation on grain moisture and temperature are not included. Electrical energy for winter aeration is not tabulated.

FIGURE 13. Fan management strategy for the CORNDRY model (Van Ee and Kline, 1979b)
controls are provided. The starting date for humidistat controls is also available.

7. A new numerical zero-searching technique is provided to save computing time. One program fits all cases.

8. The potential yield data for years, the growing degree day unit for the silking stage, and calendar days for maturity are used as inputs at the I/O unit so that the user will have freedom in handling the program. As a matter of fact, this model can be applied for any location and any year range without a need of changing the program itself.

9. Different combinations of drying theories are selectable without a need of changing the content of program.

10. Characteristics of grain resistance to airflow can be adjusted by the percentage of the fine material in corn (BCFM).

11. Data of fan characteristics can be used as an input for individual bins, or, a user can simply choose the default curve developed by Van Ee and Kline (1979b). Bins need not be of equal sizes.

12. Drying with supplemental heat is allowed.

13. Output of grain flow and drying conditions can be printed out on files or as hard copy.
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Algorithms of the CORNDRY model

Several parameters were considered by Van Ee and Kline (1979b) in determining the stages of corn growth. In the following sections, we will describe some of these important parameters and related algorithms.

Potential Yield

The potential yield for each year was taken from the Iowa Corn Yield Test Report. In this report, more than 130 varieties were usually under test in each of seven districts every year in Iowa. Comparisons of the same variety from this yield report are difficult because a similar variety usually does not last too long.

To simplify this situation, we assume that the yearly average of each district is equal to that of the medium season corn. According to Morey et al. (1971a), the yield differences between short, medium and long season corn are about 5-10%.

In Van Ee and Kline’s report (1979a), however, the difference for central Iowa are about 10 bushels per acre between two subsequent levels. Table 4 shows the potential yield of medium season corn in northwestern Iowa. For this study, the long and short season corn yields are estimated by adding to and subtracting from that of the medium season by 10 bushels per acre.

Planting

Like the CORNSIM model, CORNDRY assumes that planting starts on April 1 each year. There are three factors that affect the planting activity, namely, the field working condition, the good working days
TABLE 4. Maximum potential yield of medium season corn for northwestern Iowa\(^a\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield, bu/ac(^b)</th>
<th>Year</th>
<th>Yield, bu/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>107.2</td>
<td>1970</td>
<td>109.2</td>
</tr>
<tr>
<td>1961</td>
<td>106.9</td>
<td>1971</td>
<td>125.4</td>
</tr>
<tr>
<td>1962</td>
<td>111.7</td>
<td>1972</td>
<td>140.0</td>
</tr>
<tr>
<td>1963</td>
<td>116.7</td>
<td>1973</td>
<td>121.3</td>
</tr>
<tr>
<td>1964</td>
<td>114.1</td>
<td>1974</td>
<td>96.9</td>
</tr>
<tr>
<td>1965</td>
<td>85.2</td>
<td>1975</td>
<td>129.1</td>
</tr>
<tr>
<td>1966</td>
<td>106.9</td>
<td>1976</td>
<td>115.3</td>
</tr>
<tr>
<td>1967</td>
<td>101.9</td>
<td>1977</td>
<td>113.6</td>
</tr>
<tr>
<td>1968</td>
<td>95.7</td>
<td>1978</td>
<td>141.3</td>
</tr>
<tr>
<td>1969</td>
<td>154.2</td>
<td>1979</td>
<td>141.2</td>
</tr>
</tbody>
</table>

\(^a\)Yields for the long and short season corn are each 10 bushels more or less than this value.

\(^b\)Data are from the Iowa Crop Improvement Association (1960-1979).

reserved for tillage operations and the first planting date preset for different varieties of corn in management strategies. A maximum of 30 fields can be assigned for a 300-acre farm. Late planting usually reduces the corn yield in the end. Yield reductions due to this reason are taken into account, as shown in Table 5, by corn variety and the planting date.

**Corn Growth**

Three stages are usually included in simulation of the plant development. The first stage, the vegetative growth stage, is when corn grows from planting to silking. The second stage, the ear growth stage, continues from silking to kernel setting or to a moisture of 75% in
TABLE 5. Daily yield reductions due to late planting$^a$

<table>
<thead>
<tr>
<th>Corn Variety</th>
<th>Yield Reductions, bu/ac/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May 5-15</td>
</tr>
<tr>
<td></td>
<td>(125-135)$^b$</td>
</tr>
<tr>
<td>full</td>
<td>0.5</td>
</tr>
<tr>
<td>medium</td>
<td>0.0</td>
</tr>
<tr>
<td>short</td>
<td>0.0</td>
</tr>
</tbody>
</table>

$^a$Data from Van Ee and Kline (1979b).
$^b$Julian date.

corn. And, finally, the third stage is the period of corn drydown in the field until harvest.

**Vegetative Growth Stage**

A method of accumulation of growing degree units developed by Newman et al. (1968) has been used by Van Ee (1979) and Morey et al. (1971a) to simulate the first vegetative growth stage. According to Newman et al. (1968), the growing degree units for each day are calculated as follows:

\[
GDU = \frac{(T_{\text{max}} + T_{\text{min}})}{2} - 50^\circ F
\]

where
- $GDU = \text{growing degree units per day.}$
- $T_{\text{max}} = \text{maximum daily temperature, } ^\circ F.$
- $T_{\text{max}} = 86 ^\circ F, \text{ if } T_{\text{max}} > 86 ^\circ F.$
- $T_{\text{min}} = \text{minimum daily temperature, } ^\circ F.$
- $T_{\text{min}} = 50 ^\circ F, \text{ if } T_{\text{min}} < 50 ^\circ F.$
This GDU is accumulated by day and compared with the preset requirement beginning when corn is planted. The total GDU for corn varies with corn variety and field latitude. Generally speaking, the further north, the less the need for GDU to grow corn, regardless of corn yield. However, long season corn usually needs more GDU than short ones. For the Iowa area, Van Ee (1979) described these requirements as in Table 6. These GDU data are directly inputed to model for each CORNDRY run.

**TABLE 6. GDU requirements of corn for the first stage**

<table>
<thead>
<tr>
<th>Corn Variety</th>
<th>GDU</th>
</tr>
</thead>
<tbody>
<tr>
<td>full</td>
<td>1420</td>
</tr>
<tr>
<td>medium</td>
<td>1320</td>
</tr>
<tr>
<td>short</td>
<td>1250</td>
</tr>
</tbody>
</table>

(Data are taken from Van Ee and Kline (1979b).

**Ear Growth Stage** Morey et al. (1971a) combined this stage with the first stage simply by using the GDU criteria to cover both stages. Van Ee (1979), on the other hand, used the number of calendar days for this stage as reported by Schmidt and Hallauer (1966) to simulate the corn growth during this period. For Iowa conditions, twenty-two calendar days are considered accurate enough for three varieties of corn to grow from silking to the beginning of the dry-down stage. To generalize the CORNDRY model in applications, these calendar dates are
also arranged as a user's input for each run.

**Dry-Down Stage**

Van Ee and Kline (1979a) developed a dry-down algorithm which they proved accurate in simulating the change of corn moisture in the field. Empirical equations are shown as follows:

\[
RD = 1.0 \left( -2.0 + 0.47 \text{ DB} \right) \quad \text{when } 75\% > \text{MC} \geq 50\%.
\]

\[
RD = 0.9 \left( -0.54 + 0.021 \text{ DB} \right) \quad \text{when } 50\% > \text{MC} \geq 37\%.
\]

\[
RD = 0.8 \left( -0.08 + 0.119 \text{ WBDPRS} \right) \quad \text{when } 37\% > \text{MC} \geq 25\%.
\]

For the moisture range of 25% to 20% (included):

\[
RD = 0.8 \left( -0.432 + 0.146 \text{ WBDPRS} \right) \quad \text{when } \text{RD} \geq 0.
\]

\[
RD = \text{Min} \left[ 0, 0.05 \left( \text{MC} - (\text{EMC} + 1) \right) \right] \quad \text{when } \text{RD} < 0.
\]

\[
RD = 0.05 \left( \text{MC} - (\text{EMC} + 1.0) \right) \quad \text{when } 20\% > \text{MC} > \text{EMC}
\]

where \( \text{MC} \) = grain moisture, %.

\( \text{RD} \) = kernel moisture reduction, %/point/day.

\( \text{DB} \) = dry bulb air temperature, °F.

\( \text{WBDPRS} \) = wet bulb depression, °F.

\( \text{EMC} \) = equilibrium moisture content, %.

**Freeze Damage**

During dry-down stage, damage due to freezing weather is considered. The first freezing condition occurs when the minimum air temperature is less than 28 °F, and damage results when corn moisture in the field is still higher than 33% at the same time. CORNDRY, like CORNSIM, estimates the freezing loss by using a 2.5% yield reduction for each percent of moisture above 33%, or
\[ YD = 0.025 \times (MC - 33) \times \text{YIELD} \]

where \( YD \) = yield reduction due to frost damage, bu/ac.
\( \text{YIELD} \) = corn yield (= potential yield - late planting penalty)

bu/ac.
\( MC \) = grain moisture, %.

Harvest

Harvest starts when any of the fields meets the requirements of the user's specified initial harvest moisture and date, the field working condition, and the drying potential capacity of the system. Once begun, harvesting proceeds from the driest field and then to the next driest until all fields are harvested.

The total quantity harvested per day is then determined by the combine rate, working hours, and the drying capacity of the system. Preharvest loss and combine loss are calculated using the coefficients shown in Table 7 with equations expressed as follows:

\[ YD = \text{YLDCOM} + \text{YLDHAR} \times (\text{JULDAY} - \text{DAYC}) \]

where \( \text{YLDCOM} \) = yield loss due to combine operation, bu/ac.
\( \text{YLDHAR} \) = field loss due to preharvest, bu/ac.
\( \text{JULDAY} \) = Julian day.
\( \text{DAYC} \) = day constants in Table 7.
\( YD \) = total yield loss during harvest, bu/ac.
TABLE 7. Harvest yield loss

<table>
<thead>
<tr>
<th>Date</th>
<th>Julian date</th>
<th>Preharvest loss, bu/ac/day (YLDHAR)</th>
<th>Combine loss bu/ac (YLDCOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Oct. 1</td>
<td>≤ 275</td>
<td>0.</td>
<td>2.0</td>
</tr>
<tr>
<td>Oct. 1 to Nov. 16</td>
<td>≤ 320</td>
<td>0.2</td>
<td>3.0</td>
</tr>
<tr>
<td>After Nov. 16</td>
<td>&gt; 320</td>
<td>0.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

*Data taken from Van Ee and Kline (1979b).

Filling Strategies

The controlled-filling strategy is dependent on the minimum airflow rate in bins. Theoretically, this minimum requirement of airflow rates (in cfm/bu) should be maintained in the drying bin all the time, even after the new harvested grain is added in. This will make sure that grain in the bin is dried to a safe moisture level and the danger of spoilage during storage is minimized. In an actual process, the possible grain depth to be added is calculated first with the minimum airflow rate, which corresponds to the moisture of harvested grain as in Figure 14. The amount of grain harvested is therefore decided by deducting the depth of the wet grain in bin from the possible grain depth.

A typical outline of optimum controlled strategies is summarized in Figure 15.
FIGURE 14. Relationship of minimum airflow rate and grain moisture

Grain in Bins and Shrinkage

Grain loaded into a bin will be maintained in layers until drying is completed. Each layer has its own grain depth, moisture and temperature. A maximum of 20 layers can be assigned by the user. The original depth of each layer will be the same and equals the bin height divided by the total layers specified. Grain totalling more than the
1. Begin filling as soon as the harvested grain moisture is 26% or less.
2. The maximum daily filling depth is 4 ft for harvested grain at less than 24%, and 2 ft for moisture above 24%.
3. If harvested grain moisture exceeds 22%, additional fill is not allowed until the drying front at least passes halfway up through the grain bed.
4. The quantity of grain added can be expressed by these equations:

\[
FILL = \left( \frac{AIR \times 1.245}{Q_{\text{min}}} - WGD \right)
\]

After adjusted by the bin depth,

\[
FILL_{\text{adjusted}} = \min \left( FILL + \text{DEPTH}, \text{BINH} \right) - \text{DEPTH}
\]

in which
- \( \text{AIR} \) = airflow rate in bins, cfm/ft².
- \( Q_{\text{min}} \) = minimum airflow rate from Figure 14, cfm/bu.
- \( \text{FILL} \) = potential additional filling depth, ft.
- \( \text{DEPTH} \) = grain depth in bins, ft.
- \( \text{BINH} \) = bin height, ft.
- \( \text{WGD} \) = depth of the wet grain in bin, ft.

5. Layer filling may be skipped on any day if filling quantity is too small to make filling practical.
6. Once the filling operation starts in one bin, it will continue until that bin gets the same quantity of grain as that of the first assigned. This filling operation for the bin may last one or two days before filling other bins begins.

FIGURE 15. Controlled-filling strategy (Van Ee and Kline, 1979b)
bin capacity is allowed in the model but the extra amount will be pooled in the 20th layer. This is one reason that the layer depths vary during drying.

Another cause of depth changes during drying is grain shrinkage which relates to grain moisture changes. The shrinkage rate per percent of moisture reduction is shown as in Table 8, which is derived from Brooker et al. (1974).

**TABLE 8.** The percentage of corn shrinkage per % point of moisture decrease

<table>
<thead>
<tr>
<th>Moisture range</th>
<th>Shrinkage in vol. of grain /% point of moisture decrease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;25 %</td>
<td>1.0</td>
</tr>
<tr>
<td>25 -17 %</td>
<td>1.3</td>
</tr>
<tr>
<td>17 -15 %</td>
<td>1.5</td>
</tr>
<tr>
<td>15 &gt;</td>
<td>1.7</td>
</tr>
</tbody>
</table>

aData derived from Brooker et al. (1974).

**Characteristics of Fan**

Airflow rate is determined from the characteristics of the fan and the airflow resistance curves. Two options for the source of fan curve are provided: one is the Van Ee's approximate curve (Van Ee, 1979), the other is the manufacturer's fan curve. Figure 16 shows a comparison of the Van Ee's approximate curve and a Rolfes fan at the same power rating. In this particular case, the Van Ee's approximate curve gives
lower airflow rates than the actual fan curve does. The difference increases as the static pressure or the grain depth increases to its normal range. Nevertheless, this approximate curve still offers a great advantage in an operational research, and therefore will be adopted in this study. To use the manufacturer's fan curve, data can be inputed to model by arbitrarily selecting a maximum of ten pairs of pressure and airflow rates. These data will be used to compute the relevant point by an interpolation method.

Van Ee's approximate fan curve is expressed as the following equation:

\[ Q = KW \times \left( \frac{2412.87 - 321.7 \times PP}{AREA} \right) \]

where

- \( KW \) = rated fan power, kW.
- \( PP \) = static pressure of fan, in.
- \( AREA \) = bin cross-section area, \( \text{ft}^2 \).

The loading curve for corn from Hukill and Shedd (1955) is:

\[ PP = DEPTH \times 0.00065 \times Q \times Q / \log (1 + 1.156 \times Q) \times PACK \]

in which \( PACK = 1.5 \) if BCFM is not specified.

\[ = 1. + (14.5566 - 0.1342 \times Q) \times BCFM \]

\( Q \) = airflow rate, cfm/ft\(^2\).

BCFM = content of broken corn and foreign material, decimal.

DEPTH = grain depth, ft.
FIGURE 16. Comparisons of fan characteristics of Rolfes axial fan and approximation curve of Van Ee and Kline (1979b)
By using root-searching technique, the airflow rate and static pressure for each combination of grain depth can be found easily in the subroutine FAN. However, this solution also can be found graphically as in Figure 17.

To find an operating point on a fan curve with the fan power known, the bin diameter and the grain depth are required. For a first try on Figure 17, start at an arbitrary point on the Shedd's curve with a pack factor of 1.5 in the lower left corner of the graph, and draw two lines horizontally and vertically to meet proper lines of the bin diameter (30 ft) and the grain depth (12 ft) respectively. From those two intersection points, again, draw vertical and horizontal lines respectively from those two intersection points, trying to make both new lines meet on a desired fan curve (7.46 kW).

In this particular case, these two points a and b fail to meet. For a rough estimation, the midpoint c along the fan curve is the best answer. However, a second try might start from point c along the previous loop to obtain another closer point on the fan curve. In fact, you will find out point c is close enough for use.

**Drying Models**

Thompson's (1972) equilibrium model is based on the following equations:

A mass balance between air and grain:

\[ H_f = H_o + (H_o - H_f) \times 100 / R \]
FIGURE 17. Graphical method of finding airflow rate and static pressure for different bins and grain depths.
A heat balance between air and grain:

\[
T_f = \frac{(0.24 + 0.45 H_o)T_o + RG_o + (H_o - H_f)(1092.8 - G_o)}{(0.24 + 0.45 H_f) + R}
\]

Equilibrium condition between air and grain moisture:

\[
RH = 1 - \exp \left[ -3.82E-5 \times (T_f + 50) \times M_f \times M_f \right]
\]

Saturated air vapor pressure:

\[
P_s = \exp \left[ 54.6329 - \frac{12301.69}{T_f} - 5.16923 \times \log(T_f) \right]
\]

when \( T_f > 32^\circ F \).

Partial vapor pressure of air:

\[
P_v = RH \times P_s
\]

Absolute air humidity:

\[
H_f = 0.6219 \times P_v / \left( 14.696 - P_v \right)
\]

in which \( M_o, M_f = \) initial and final grain moisture, %

\( H_o, H_f = \) initial and final absolute air humidity,

1 lb of water/1 lb of dry air.

\( R = \) grain-air ratio, 1 lb of grain/1 lb of air.

\( T_o, T_f = \) initial and final temperature, °F.

\( G_o = \) grain temperature, °F.

\( RH = \) relative humidity, %

\( P_s, P_v = \) saturated and partial vapor pressure, psia.
HFIND is a function subroutine to solve for a new $H_f$ from a given $H_f$ by following the sequence of these equations. Four or five iterative loops can obtain a desired solution for a given condition.

For a graphical expression of this equilibrium model, at least three of the above equations can be solved by using Figure 18. This graph is drawn by superimposing the equilibrium moisture equation on top of a psychrometric chart. The drying process can be represented by a wet-bulb line assuming that the heat content of grain is small and is neglected (the actual process will proceed along the dashed line). This graph is useful to be a rough check for results calculated from the above balance equations.

Thompson's equilibrium model was not very accurate in predicting the moisture profile of grain layers during a drying operation (Sharp, 1982). It tends to overdry the bottom layers and, consequently, distorts the moisture gradients.

Many efforts have been made to adjust the predicted results of this model by incorporating thin layer drying equations (Morey et al., 1979a; Pierce and Thompson, 1980a; Pfost et al., 1976; Van Ee and Kline, 1979b). For a low temperature drying, equations of this nature developed by Sabbah (Flood et al., 1972), Troeger (Troeger, 1967) and Misra and Brooker (1979) are usually accepted.

The problem of using thin layer drying equations alone for the model is the same as that of Thompson's pure equilibrium model, because, in our model, each layer is 0.8 to 1 ft deep which is hardly thin. An overdrying problem still results.
FIGURE 18. Graphical method of solving the equilibrium model
To solve this problem, Morey et al. (1979a) and Van Ee (1979) combined Thompson's model and Sabbah's thin layer drying equation by calculating both at the same time and selecting the one with the least moisture change in each layer as the final solution. Mittal and Otten (1982) employed the same technique but took the Misra and Brooker (1979) thin layer equation in the place of Sabbah's. The new arrangement will be accepted in the CORNDRY model throughout the study. The reasons of using this modification are that:

1. The Misra and Brooker (1979) equation is suitable for a low temperature drying. Its temperature range is from 36 to 160 °F, which covers the range of air conditions in our study.

2. There are many drying parameters considered in this equation, such as air temperature, relative humidity, airflow rate, and initial moisture content of grain. Data for these parameters are accessible in this model.

3. Equation is easy to program. No repetitive calculations are needed. The computing time is thus shortened.

Like the Morey model (Morey et al., 1979a), a hysteresis effect between the sorption and desorption isotherms relating equilibrium moisture content to equilibrium relative humidity of the air is also considered in the model. Both sorption and desorption equations used in this study were developed by Thompson (Thompson, 1972; Morey et al., 1979a).
Grain Deterioration

Deterioration of grain during drying and storage processes was studied by Steele et al. (1969) and later summarized by Thompson (1972). The related equations will not be repeated here but the reader might refer to the STORE subroutine in Appendix D, or, Figure 19, in which both the safe storage time, effective hours and deterioration rate can be solved by a graphical method. The data in Figure 19 have been updated by using Saul's (1970) equation. The lower portion of the graph can be used to predict the deterioration rate and equivalent hours—the time that has been spent as a fraction of 230 hours. The period of 230 hours is a time criterion that causes 0.5% dry matter loss in grain during drying or storage (Steele et al., 1969).

For example, at 44°F grain temperature and 20% moisture, the safe storage time is about 120 days. To find the equivalent hours and deterioration rate for storing a grain under the same conditions for 80 days, draw a vertical line a-b and then connect 0-b. After that, draw a vertical line from 80 days to meet 0-b line at c, from c draw a horizontal line to meet the curve at d and the vertical axis at f. From points d and f, the equivalent time is 150 hours and the deterioration rate is 0.3% for a storage time of 80 days.

The temperature rise and moisture increase due to dry-matter decomposition are computed using the following equations:

\[
G_{\text{TEMP}}(i+1) = G_{\text{TEMP}}(i) + 67.72 \times \text{DTRAT} / C_g
\]

\[
G_{\text{MCDB}}(i+1) = G_{\text{MCDB}}(i) + 0.6 \times \text{DTRAT}
\]
FIGURE 19. Relationship of safe storage time and grain moisture and temperature
where

\[ \text{DTRAT} = \text{increase of deterioration rate, \%} \]
\[ \text{GTEMP} = \text{grain temperature, °F}. \]
\[ \text{GMCDB} = \text{grain moisture, \%}. \]
\[ C_g = \text{specific heat of grain, Btu/lb-F°}. \]
\[ i = \text{day sequence}. \]

Root Searching Technique

Several occasions such as finding airflow rate, solving the equilibrium model, and calculating the saturation status of air humidity, need to employ an iterative searching technique to find a final solution. Most researchers used a bisection or an equivalent method to solve this sort of problem (Thompson et al., 1968; Bakker-Arkema et al., 1974; Van Ee, 1979). Disadvantages of this method include:

1. It needs more iterations to complete a job.
2. The user must specify two limiting values.
3. It requires complex programming.

The fixed-point technique, which can be widely found in recent textbooks of numerical analysis, will be stated here and used for our model. Figure 20 depicts an example of how to find an airflow rate in a loading bin.

First of all, the fan curve and the resisting curve should be arranged into forms of following equations:

\[ P_i = f' (Q_i) \]
FIGURE 20. Sketches for finding an appropriate value in an iterative technique
and

\[ Q_{i+1} = f(P_i) \]

Combine these two equations,

\[ Q_{i+1} = f[f'(Q_i)] = F(Q_i) \]

in which \( P, Q \) = variables in consideration.

\( f, f', f = \) functions.

\( i = \) the sequence number in calculation.

From the last equation above, setting \( i=1 \), \( Q_2 \) can be evaluated when \( Q_1 \) is known. Theoretically, a final \( Q \) can be obtained if this equation is repeated with the new calculated \( Q \) inserted into the right-hand side of the equation. This is the so-called fixed-point technique.

To avoid a diversion of the solution which might occur when the first two equations are not arranged well, the fixed-point method was modified by using a proportion technique.

From Figure 20a and b, suppose we have found \( Q_2 \) and \( Q_4 \) from given \( Q_1 \) and \( Q_3 \). By similarity of two shadow triangles as shown in Figure 20b, a final closest point \( Q_5 \) can be found from this relationship:

\[ \frac{(Q_5 - Q_3)}{(Q_3 - Q_1)} = \frac{(Q_4 - Q_3)}{[(Q_2 - Q_1) - (Q_4 - Q_3)]} \]

or,

\[ Q_5 = Q_3 + (Q_3 - Q_1) \frac{(Q_4 - Q_3)}{[(Q_2 - Q_1) - (Q_4 - Q_3)]} \]
To find $Q_5$ for the first loop, let $Q_3 = (Q_1 + Q_2)/2$ and for the other loops, let $Q_3 = Q_5$ until a desired answer is obtained.
CORNDRY SUBROUTINES

CORNDRY is a collection of FORTRAN subroutines which functions in simulating the filling and drying operations. These subroutines include PLANT, FLDDRY, FREEZE, HARV, PRINT1, PRINT2, CONTRL, DISFIL, BINFIL, DRYMOD, DRYING, STORE, FAN, and INFO. The first four subroutines were taken directly from the CORNSIM model with few modifications. Others were developed in this study.

Functions of the CORNDRY model can be described as a flow-chart shown in Figure 21. The interconnection between the main program and other subroutines is shown as in Figure 22.

PLANT--Functions of PLANT subroutine include:
1. Assigning the plot number and corresponding acreage.
2. Recording the planting date.
3. Calculating the penalty due to late planting.
4. Finding the potential yield for each plot.

FLDDRY--Subroutine FLDDRY mainly handles the moisture change in the field and chooses the plot with the least moisture content of corn for harvest. The drydown moisture of corn on the field will be printed out by day until all plots are harvested.

FREEZE--Subroutine FREEZE decides the air freezing condition and calculates the damage due to early freezing. A message of freezing will be printed out. Freezing condition, however, is only checked once a year.

HARV--In CORNDRY, HARV is incorporated with the CONTRL subroutine to decide the quantity of corn in the field to be harvested. Functions
FIGURE 21. A flow-chart of the CORNDRY model
FIGURE 22. Interconnection between the main program and other subroutines in the CORNDRY model
of HARV are mainly to calculate the yield penalty for late harvest in that particular plot and to monitor the remote message of the potential loading of the present drying system. HARV also records the quantity, moisture content and acres harvested that day.

PRINT1--This subroutine is used to print out the conventional CORNSIM reports. Outputs for different plots include field number, corn type, dates for planting, silking, maturity and harvesting, planted acres, potential yield, planting loss, frost loss, field loss and harvest yield, harvest moisture and acres left in the field. A typical output is shown in Appendix B.

CONTRL--Subroutine CONTRL can be activated if corn in the field is ready to be harvested. Basically, CONTRL calculates the maximum quantity the drying system allows to load grain in according to different schedules and calls HARV to harvest that amount if possible. After the harvested grain is obtained, CONTRL then notifies the DISFIL subroutine to distribute the fresh grain to appropriate bins. The message from DISFIL will be fed back to CONTRL which then asks HARV to harvest more if bins are still available.

Information of this arrangement will be printed out as shown in Appendix B. However, CONTRL will not be activated when the field working condition is no good or the harvest starting date is not yet reached.

DISFIL--The main purpose of DISFIL is to assign the harvested grain to a proper bin. Various arrangements of bin loading can be processed in this subroutine. Once a bin accepts a certain quantity of grain to
it, DISFIL will then record the related information such as total bushels in bin, and date of loading, for future use. Before it finishes the operation, DISFIL turns the fan on and calls the FAN subroutine to calculate the corresponding airflow rate and static pressure, and then calls the BINFIL subroutine to arrange each load by layers for drying.

**FAN**—The FAN subroutine is to determine the airflow rate and static pressure of the bin as new grain is coming in. FAN uses Shedd's resistance curve and fan data which may be provided by the user or directly taken from Van Ee's approximate equation. A zero-searching technique is used in the subroutine to find the intersection of both curves.

**BINFIL**—Purpose of this subroutine is to divide the new coming grain into appropriate layers and mixes it with the old grain for the contacting layer. Excess grain will be put into the 20th layer, which is the maximum layer the user can specify in this model. BINFIL also calculates the grain depth of each bin and the initial moisture of each layer.

**DRYING**—The subroutine DRYING, the essence of the CORNDRY model, will manage the drying process by layers. The air temperature rise due to motor and fan inefficiency is calculated first and added to air as along with supplemental heat, if any. The user should be aware of a fact that, for a supplemental heat, the input figure less than 100 will be expressed as °F unit; while larger than 100 will be expressed as Btu/min unit. The main inputs are air temperature and
relative humidity. Several drying methods and their combinations are introduced in this subroutine to obtain a better result for the same condition, but only the Thompson's equilibrium model with a modified version is used in this study. Calculations are made layer by layer upward and a root-searching technique is applied each time.

DRYMOD—Following DRYING mode, DRYMOD is a housekeeping subroutine which takes care of calculations such as finding the drying front layer and its corresponding depth, the cumulative hours and kilowatthours of fan operation, the average moisture content and grain temperature throughout the whole grain depth. There are two other functions built into the DRYMOD subroutine—the shrinkage of grain depth of each layer during drying and the operation of the fall shutdown schedule.

STORE—During drying and winter holding periods, the STORE subroutine should be called to calculate the safe storage time and deterioration rate of grain by day. In the winter holding period, STORE can also activate the DRYING and DRYMOD subroutines to aerate the storage bins when the grain temperature is higher than a preset limit.

PRINT2—The PRINT2 subroutine handles outputs of air and grain properties and other related data of bins both on hard copy and on disk files—BIN1, BIN2, BIN3, and BIN4. Typical forms of this output can be found in Appendix B.

INFO—The INFO subroutine has several functions:

1. It inputs the initial data related to bins and fans and other
control parameters.

2. It initializes the related parameters at the beginning of each year.

3. It prints out the bin arrangement form—the title page format (see Appendix B).

4. It prints out the weekly, fall shutdown, spring shutdown and final shutdown summary reports (see Appendix B).
FIELD TEST OF DRYING MODEL

Data Collections

Most researchers used data obtained from a laboratory-scale test bin to verify their models. Van Ee and Kline (1979b), on the other hand, employed both laboratory and field data to validate the Morey model. They concluded that the results were in good agreement in both high airflow and low airflow conditions. Kranzler (1977) took field data of one bin in Ames, Iowa to evaluate Thompson's equilibrium model by drying corn from 18% to 14.3% and obtained an excellent agreement between simulated and actual results. Mittal and Otten (1982), after revising Morey's model using Misra and Brooker's thin layer equation to replace the Sabbah's, conducted a validation test of their new model by using measured data from two single-fill deep bins for two years with and without supplemental heat. They also obtained a fair agreement between the measured and predicted moisture profiles.

So far, most of the reported work on the verification procedure has been done on single-fill bins. Validations on layer-filling bins dried with ambient air have not yet been reported. In order to positively assess the model capability of predicting moisture profiles at different drying periods for the layer type of loading, related data were obtained from Kline (1979) and were used for this validation purpose.

The corn moisture data were taken from two bins located at Farnhamville and Glidden, Iowa. Because both locations were almost at the midpoint between Des Moines and Sioux Falls, the weather data of
1979 for both cities were then used to verify the Mittal and Otten revised model.

Specifications of these two test bins are described in Table 9.

**TABLE 9. Specifications of the test bins**

<table>
<thead>
<tr>
<th></th>
<th>bin 1</th>
<th>bin 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Farnhamville</td>
<td>Glidden</td>
</tr>
<tr>
<td>Bin diameter</td>
<td>30 ft</td>
<td>30 ft</td>
</tr>
<tr>
<td>Bin depth</td>
<td>17.5 ft</td>
<td>17.5 ft</td>
</tr>
<tr>
<td>Bin capacity</td>
<td>10,000 bu</td>
<td>10,000 bu</td>
</tr>
<tr>
<td>Total corn</td>
<td>10,359 bu</td>
<td>10,788 bu</td>
</tr>
<tr>
<td>Initial moisture</td>
<td>22.4 %</td>
<td>22.4 %</td>
</tr>
<tr>
<td>Fan power rating</td>
<td>7.5 kW</td>
<td>7.5 kW</td>
</tr>
<tr>
<td>Supplemental heat</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 10 is an inventory of grain input for these two test bins. Both bins were not loaded at the same time. Although bin 2 was loaded later than bin 1, the loading period lasted about the same number of days. It took about 23 days to fill each bin. Maximum capacity of each bin was 10,000 bushels, but both were a little bit overloaded if the effect of grain shrinkage during loading was neglected.

**Discussions on Validation Results**

Figures 23 to 27 are the moisture profiles on Oct. 17, Oct. 29 and Nov. 6 for bin 1 and on Oct. 29 and Nov. 7 for bin 2. The initial moisture of each load was also recorded, but, because of actual
TABLE 10. Grain input schedule for bins at Farnhamville and Glidden, Iowa, 1979

<table>
<thead>
<tr>
<th>Date</th>
<th>Load</th>
<th>Total bu in bins</th>
<th>Initial grain properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bushels</td>
<td>Bin 1</td>
<td>Bin 2</td>
</tr>
<tr>
<td>79/10/2  (275)</td>
<td>5488</td>
<td>5488</td>
<td>0</td>
</tr>
<tr>
<td>79/10/11 (284)</td>
<td>2271</td>
<td>--</td>
<td>2271</td>
</tr>
<tr>
<td>79/10/14 (287)</td>
<td>2458</td>
<td>7946</td>
<td>--</td>
</tr>
<tr>
<td>79/10/15 (288)</td>
<td>2839</td>
<td>--</td>
<td>5110</td>
</tr>
<tr>
<td>79/10/21 (294)</td>
<td>1136</td>
<td>--</td>
<td>6246</td>
</tr>
<tr>
<td>79/10/25 (298)</td>
<td>2413</td>
<td>10359</td>
<td>--</td>
</tr>
<tr>
<td>79/10/27 (300)</td>
<td>2555</td>
<td>--</td>
<td>8801</td>
</tr>
<tr>
<td>79/11/02 (306)</td>
<td>1987</td>
<td>--</td>
<td>10788</td>
</tr>
</tbody>
</table>

aBin 1: at Farnhamville, Iowa.
Bin 2: at Glidden, Iowa (South bin).

shrinkage that occurs during drying, there will be an inconsistency in grain depth in the top layers.

By using Des Moines weather data, the simulated results are close to the observed data for the first period but tend to become drier for the late periods. For the Sioux Falls weather data, there is a good agreement on the bottom layers but not for the top layers. This is an expected phenomenon because the weather of Sioux Falls is supposed to be more humid than that of Des Moines and the test site is located inbetween.

After a certain time, the predicted drying front in the test bins passed through the grain depth faster than was observed, especially when the model was verified by the the weather of Sioux Falls. This
FIGURE 23. The predicted and observed moisture profile in Bin 1 on Oct. 17, 1979 (fan power rating=7.5kW)
FIGURE 24. The predicted and observed moisture profile in Bin 1 on Oct. 29, 1979 (fan power rating=7.5 kW)
FIGURE 25. The predicted and observed moisture profile in Bin 1 on Nov. 6, 1979 (fan power rating=7.5 kW)
FIGURE 26. The predicted and observed moisture profile in Bin 2 on Oct. 29, 1979 (fan power rating=7.5 kW)
FIGURE 27. The predicted and observed moisture profile in Bin 2 on Nov. 7, 1979 (fan power rating=7.5 kW)
situation reveals an inadequacy in nature of the revised model which tends to slow down the moisture changing rate at the bottom layers but to increase the drying potential of air as it passes through the rest of top layers.

Morey et al. (1979a) tried to correct this inconsistency by decreasing the actual airflow rate 20-30% in the prediction model. This sort of modification is not attempted in this study, however, because the airflow rate used in the model is obtained from the approximate fan curve, which, as has been described, already predicts the airflow rates in a conservative way.

As the drying process proceeds, the disagreement of drying front becomes less (Figure 25 and Figure 27), but the rewetting process begins to appear in the bottom layers. This is because the weather usually becomes more humid during late fall.

Figure 28 compares the change of average moisture for both bins with the predicted and the observed data. Because bin 1 is located closer to Sioux Falls, a better agreement is found in bin 1 on the moisture history predicted from the weather data of Sioux Falls. For bin 2, however, the observed moisture data points almost fall in between those two predicted curves. The possible reason of this is that bin 2 is located farther from Sioux Falls than bin 1.

Figure 29 shows the correlation between the predicted and measured moistures in two bins for two sets of weather data. Each graph consists of data points predicted from weather data of Sioux Falls and Des Moines with periods on Oct. 2, 23, 29 and Nov. 6 for bin 1 and Oct. 11, 24, 29
FIGURE 28. Comparisons of the predicted and observed average moisture history of test bins (fan power rating=7.5 kW)
and Nov. 7 for bin 2.

For bin 1, most of data points off the $Y = X$ line are in the moisture range of 18%-22%, in which predicted moistures are lower than actual ones.

The regression lines for the predicted ($Y$) and observed ($X$) moistures from two sources of weather data can be expressed as follows:

For Des Moines weather data:

$$Y = 0.09 + 0.92 \, X \quad R = .88$$

For Sioux Falls weather data:

$$Y = 5.80 + 0.65 \, X \quad R = .85$$

In all, agreements between observed and predicted moistures both throughout the grain depth and for the average moisture are judged satisfactory. From the above data shown, use of the Sioux Falls weather data for a prediction of the drying activity of northwestern Iowa is justified, even though it appears to be on the conservative side. Sioux Falls is located near the northwest corner of Iowa. Therefore, combining of prediction results both from Sioux Falls weather used in this study and from Des Moines as Van Ee (1979) has done before will enhance application of the model to the northwestern Iowa area.
FIGURE 29. The correlation between the predicted and observed moisture at different drying periods
The Base Management

In the CORNSIM model, three varieties of corn—long, medium and short season—are included. For northwestern Iowa, because of the weather, most of corn planted is of the medium and short variety. Therefore, the long season corn is excluded from our consideration. The basic management study will be focused on two schemes: one planted half with short and half with medium season corn (scheme a), the other planted all with short season corn (scheme b). The basic management strategy for this study is outlined in Table 11.

Weather data of Sioux Falls from 1960-1979 were used as the daily inputs for the CORNDRY model. Before the CORNDRY model is run, raw weather data directly from the weather service has to be run through the FLDAY model to generate appropriate field working conditions for each day.

For a 300 acre farm, four bins (maximum 6 bins) are arranged in this study to accept the harvested grain and to dry it immediately after loading. Although the bin and fan could be of any size in the original model design, in our study, identical bins and fans are assumed.

Fans are all axial type. Two levels of fan size with power ratings of 8.8 kW and 13.2 kW will be used for later comparisons. Both have the same power ratings as Van Ee (1979) reported in his paper. More detailed specifications of the drying facility are described as in Table 12.
TABLE 11. The base management strategy for the CORNDRY model

<table>
<thead>
<tr>
<th>Area of corn production</th>
<th>-- 300 acres (121.4 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum field days for tillage</td>
<td>-- 15 days</td>
</tr>
<tr>
<td>Earliest possible day planting may begin</td>
<td>-- April 26</td>
</tr>
<tr>
<td>Last day to plant full season corn</td>
<td>-- May 14</td>
</tr>
<tr>
<td>Last day to plant medium season corn</td>
<td>-- May 28</td>
</tr>
<tr>
<td>Last day to plant short season corn</td>
<td>-- June 3</td>
</tr>
<tr>
<td>Effective planting rate</td>
<td>-- 5 a/h</td>
</tr>
<tr>
<td>Hybrid selection</td>
<td>-- Medium and short</td>
</tr>
<tr>
<td>-- Short only</td>
<td></td>
</tr>
<tr>
<td>Effective field working time</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>-- 7 hours/day</td>
</tr>
<tr>
<td>May 1-14</td>
<td>-- 8 hours/day</td>
</tr>
<tr>
<td>May 15- June</td>
<td>-- 9 hours/day</td>
</tr>
<tr>
<td>Fall harvest season</td>
<td>-- 8 hours/day</td>
</tr>
<tr>
<td>Starting harvest date</td>
<td>-- Sept. 20</td>
</tr>
<tr>
<td>Begin harvest as soon as the grain moisture in the field reaches</td>
<td>-- 26% MCWB</td>
</tr>
<tr>
<td>Or, the arrival of</td>
<td>-- Nov. 1</td>
</tr>
<tr>
<td>Grain harvesting rate</td>
<td>-- 2.5 a/h</td>
</tr>
<tr>
<td>Limit of maximum harvesting rate</td>
<td>-- 300 bu/h</td>
</tr>
</tbody>
</table>

Source: Van Ee and Kline (1979b).

TABLE 12. Specifications and management of drying bins

<table>
<thead>
<tr>
<th>Bin1-Bin4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin diameter, ft</td>
</tr>
<tr>
<td>Bin depth, ft</td>
</tr>
<tr>
<td>Pack factor</td>
</tr>
<tr>
<td>Filling date</td>
</tr>
<tr>
<td>Initial %MCWB</td>
</tr>
<tr>
<td>Fan rated power, kW</td>
</tr>
<tr>
<td>Drying stops when</td>
</tr>
<tr>
<td>or, when</td>
</tr>
</tbody>
</table>
Field Dry-Down of Corn

The corn moisture decreases in the field according to the changes of its environment. Figure 30 and 31 show the history of corn moisture in the earliest and latest plots in the field for twenty years predicted for northwestern Iowa. From these graphs, a fast field drying rate can be observed in 1976 and 1977 and the slow one in 1965 and 1967.

For most years it takes about 70 days to dry corn in the field from 75% to 26%, with a drying rate of 0.72% point per day. The worst year in this range (1965) may take longer time than normal. Usually, if corn is dried at a slow rate at this stage, a postponement of the filling schedule during harvest will likely result, unless good weather that can speed the drying process occurs during subsequent periods.

Early or late planting does not affect the field dry-down pattern much for those normal years. As a matter of fact, they both maintain the same rate and same pattern in this year range (Figure 30).

Some Facts of Corn Growth and Harvest

Table 13 lists Julian dates at different stages of corn development—dates of planting, silking, maturity and harvesting. In this example, it takes about 10 days to complete the whole planting operation and about 22 days to complete the harvesting operation. In total, more than five months (161 days) are required to complete the whole crop. These results are close to the average of 1972-1976, as reported by the Iowa Crop and Livestock Reporting Service (1977).
FIGURE 30. Corn moisture in the field versus Julian date for 1960-1979 (for the earliest plots)
FIGURE 31. Corn moisture in the field versus Julian date for 1960-1979 (for the latest plots)
Many factors such as weather, fan size and field working condition may affect the harvest operation. As Table 13 indicates, the longest harvest schedule as appears in 1972 and 1969, takes more than 30 days to complete the whole harvesting operation. Both are abnormal cases in this year range, and, usually make the later drying process more difficult.

From Table 11, we see that the combine can harvest 2.5 acres per hour, or 20 acres a day. For a 300-acre farm, therefore, it will take about 15 days to finish the whole harvesting operation without any interference. Most years as shown in Table 13 take longer than 15 days for the whole process. Delay of harvest is expected to occur due to weather conditions and the drying capacity.

In general, the weather affects the harvest operation in two ways: one is in the field work condition, the other is in the system drying capacity. Table 14 reveals some possible delays during the harvest and drying operation. In the base management, the first harvest date is set on September 20 (or, Julian days=263). After this starting date, the time of delay amounts to about 14 days due to high moisture of corn and to 2.7 days due to bad field conditions, before the first harvest operation is in effect.

During the harvesting period, average delay due to non-workable days amounts to 2.9 days. In other words, delay due to system capacity or the controlled strategy applied is about 4 days on the average. During the severe year of 1972, for example, delay due to system limitation is about 15 days. This could be reduced appreciably by
TABLE 13. The Julian dates and number of days of events during corn development<sup>a</sup>

<table>
<thead>
<tr>
<th>Year</th>
<th>Planting</th>
<th>Silking</th>
<th>Maturity</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>116(13)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>204( 3)</td>
<td>270( 3)</td>
<td>281(16)</td>
</tr>
<tr>
<td>61</td>
<td>116(11)</td>
<td>204( 3)</td>
<td>271( 6)</td>
<td>280(20)</td>
</tr>
<tr>
<td>62</td>
<td>118( 9)</td>
<td>197( 4)</td>
<td>261( 5)</td>
<td>275(20)</td>
</tr>
<tr>
<td>63</td>
<td>116(11)</td>
<td>193( 4)</td>
<td>256( 5)</td>
<td>272(19)</td>
</tr>
<tr>
<td>64</td>
<td>116(16)</td>
<td>195( 4)</td>
<td>271( 5)</td>
<td>280(19)</td>
</tr>
<tr>
<td>65</td>
<td>121( 9)</td>
<td>206( 5)</td>
<td>292( 7)</td>
<td>305(28)</td>
</tr>
<tr>
<td>66</td>
<td>116( 9)</td>
<td>197( 3)</td>
<td>266( 3)</td>
<td>281(20)</td>
</tr>
<tr>
<td>67</td>
<td>117( 8)</td>
<td>206( 5)</td>
<td>274( 7)</td>
<td>286(17)</td>
</tr>
<tr>
<td>68</td>
<td>116( 9)</td>
<td>202( 4)</td>
<td>271( 3)</td>
<td>284(21)</td>
</tr>
<tr>
<td>69</td>
<td>116( 9)</td>
<td>203( 4)</td>
<td>267( 6)</td>
<td>279(30)</td>
</tr>
<tr>
<td>70</td>
<td>116( 9)</td>
<td>195( 5)</td>
<td>253( 5)</td>
<td>265(26)</td>
</tr>
<tr>
<td>71</td>
<td>118( 8)</td>
<td>197( 5)</td>
<td>255( 5)</td>
<td>263(23)</td>
</tr>
<tr>
<td>72</td>
<td>116(14)</td>
<td>204( 4)</td>
<td>267(10)</td>
<td>281(35)</td>
</tr>
<tr>
<td>73</td>
<td>116(10)</td>
<td>198( 4)</td>
<td>260( 3)</td>
<td>277(23)</td>
</tr>
<tr>
<td>74</td>
<td>117( 8)</td>
<td>200( 4)</td>
<td>268( 5)</td>
<td>276(18)</td>
</tr>
<tr>
<td>75</td>
<td>116(14)</td>
<td>197( 3)</td>
<td>258( 9)</td>
<td>274(16)</td>
</tr>
<tr>
<td>76</td>
<td>116( 9)</td>
<td>194( 4)</td>
<td>249( 4)</td>
<td>263(16)</td>
</tr>
<tr>
<td>77</td>
<td>116(11)</td>
<td>186( 4)</td>
<td>251( 3)</td>
<td>263(27)</td>
</tr>
<tr>
<td>78</td>
<td>116( 9)</td>
<td>201( 5)</td>
<td>263( 5)</td>
<td>273(23)</td>
</tr>
<tr>
<td>79</td>
<td>120( 8)</td>
<td>201( 4)</td>
<td>267( 4)</td>
<td>276(21)</td>
</tr>
</tbody>
</table>

Average 116(10) 199( 4) 260( 5) 277(22)
Check<sup>c</sup> (120) (191) (248) (278)

<sup>a</sup>Data are four bins combined, the results are run on a 7.5 kW fan.

<sup>b</sup>Inside the parenthesis are the days for all plots to finish the same operation in that year.

<sup>c</sup>Data reported from Iowa Crop and Livestock Reporting Service (1977).
### TABLE 14. Days of delay before and during harvest for a farm planted with two schemes\(^a\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Before harvest</th>
<th>During harvest</th>
<th>Drying stops</th>
<th>Air conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Due to MC(^b)</td>
<td>Due to WD(^c)</td>
<td>Due to WD</td>
<td>Total WD</td>
</tr>
<tr>
<td>60</td>
<td>18(17)(^d)</td>
<td>6(6)</td>
<td>0(0)</td>
<td>16(16)</td>
</tr>
<tr>
<td>61</td>
<td>17(16)</td>
<td>5(5)</td>
<td>3(3)</td>
<td>20(20)</td>
</tr>
<tr>
<td>62</td>
<td>12(9)</td>
<td>3(0)</td>
<td>4(7)</td>
<td>20(23)</td>
</tr>
<tr>
<td>63</td>
<td>9(8)</td>
<td>3(3)</td>
<td>2(2)</td>
<td>19(19)</td>
</tr>
<tr>
<td>64</td>
<td>18(15)</td>
<td>4(4)</td>
<td>0(0)</td>
<td>19(19)</td>
</tr>
<tr>
<td>65</td>
<td>42(34)</td>
<td>12(12)</td>
<td>0(0)</td>
<td>28(16)</td>
</tr>
<tr>
<td>66</td>
<td>18(18)</td>
<td>1(1)</td>
<td>4(4)</td>
<td>20(20)</td>
</tr>
<tr>
<td>67</td>
<td>23(16)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>17(20)</td>
</tr>
<tr>
<td>68</td>
<td>21(18)</td>
<td>5(3)</td>
<td>4(6)</td>
<td>21(22)</td>
</tr>
<tr>
<td>69</td>
<td>17(13)</td>
<td>3(1)</td>
<td>7(9)</td>
<td>30(30)</td>
</tr>
<tr>
<td>70</td>
<td>2(1)</td>
<td>2(1)</td>
<td>10(11)</td>
<td>26(27)</td>
</tr>
<tr>
<td>71</td>
<td>0(0)</td>
<td>0(0)</td>
<td>6(6)</td>
<td>23(23)</td>
</tr>
<tr>
<td>72</td>
<td>18(16)</td>
<td>3(2)</td>
<td>5(1)</td>
<td>35(24)</td>
</tr>
<tr>
<td>73</td>
<td>14(10)</td>
<td>4(4)</td>
<td>4(2)</td>
<td>23(21)</td>
</tr>
<tr>
<td>74</td>
<td>13(12)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>18(18)</td>
</tr>
<tr>
<td>75</td>
<td>11(8)</td>
<td>1(1)</td>
<td>0(0)</td>
<td>16(19)</td>
</tr>
<tr>
<td>76</td>
<td>0(0)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>16(16)</td>
</tr>
<tr>
<td>77</td>
<td>0(0)</td>
<td>0(0)</td>
<td>8(8)</td>
<td>27(26)</td>
</tr>
<tr>
<td>78</td>
<td>10(8)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>23(20)</td>
</tr>
<tr>
<td>79</td>
<td>13(13)</td>
<td>1(1)</td>
<td>1(1)</td>
<td>21(19)</td>
</tr>
</tbody>
</table>

\(^{\text{Ave.} 13.8(11.6) 2.7(2.2) 2.9(3) 22(21)}\)

\(^a\) Scheme a: planted half for medium and half for short corn.

\(^b\) Scheme b: planted all with short corn.

\(^c\) Corn moisture in the field, %MCWB.

\(^d\) Field workdays.

\(^{\text{Inside parentheses are data for the 300 acres planted with all short season corn.}}\)
increasing the fan horsepower.

For the all short-season corn planted (scheme b), the dates are relatively shortened. During the planting and harvesting periods, they have been reduced about two days, but delay due to field working conditions seems not to be reduced accordingly.

During the drying period, air temperatures less than 25 °F and relative humidities higher than 80% will cause the model to turn off the drying process. However, the latter condition is only in effect after Nov. 20. In this study, the drying process has been shut off by these two reasons about 12.5 days each year (7.5 kW fan used).

Yield Response

Corn that suffers frost damage usually has less yield production. Table 15 shows the yield response and corresponding harvest moisture contents predicted by the CORNDRY model.

The amount of frost damage can be a good indicator of the yield response since the years that have suffered frost damage usually have less corn yield. Moisture of corn during harvest ranges from 26.0% to 18.0% MCWB. Normally, the longer the harvest is delayed, the lower the corn moisture will become when corn is harvested.

Discussion of Drying Results

Figure 32 to 34 shows related bin drying data for a typical year of 1960. Relative humidity is a decisive factor throughout the drying process. For a normal weather year like 1960, however, relative
### TABLE 15. Properties of corn at harvest

<table>
<thead>
<tr>
<th>Year</th>
<th>Frost damage bu/ac</th>
<th>Field %fill</th>
<th>Total harvested bushels</th>
<th>Init.-Final (av.) %MCWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0.</td>
<td>4.75</td>
<td>73%</td>
<td>29241.9</td>
</tr>
<tr>
<td>61</td>
<td>2.23</td>
<td>5.09</td>
<td>71%</td>
<td>28451.6</td>
</tr>
<tr>
<td>62</td>
<td>0.</td>
<td>4.23</td>
<td>75%</td>
<td>29992.0</td>
</tr>
<tr>
<td>63</td>
<td>0.</td>
<td>3.13</td>
<td>81%</td>
<td>32576.9</td>
</tr>
<tr>
<td>64</td>
<td>0.</td>
<td>5.10</td>
<td>78%</td>
<td>31199.9</td>
</tr>
<tr>
<td>65</td>
<td>26.82</td>
<td>12.03</td>
<td>31%</td>
<td>12439.1</td>
</tr>
<tr>
<td>66</td>
<td>0.</td>
<td>5.13</td>
<td>68%</td>
<td>27137.5</td>
</tr>
<tr>
<td>67</td>
<td>6.98</td>
<td>6.31</td>
<td>64%</td>
<td>25576.4</td>
</tr>
<tr>
<td>68</td>
<td>0.</td>
<td>6.30</td>
<td>64%</td>
<td>25404.9</td>
</tr>
<tr>
<td>69</td>
<td>0.</td>
<td>6.20</td>
<td>103%</td>
<td>41007.5a</td>
</tr>
<tr>
<td>70</td>
<td>0.</td>
<td>2.76</td>
<td>76%</td>
<td>30468.9</td>
</tr>
<tr>
<td>71</td>
<td>0.</td>
<td>2.67</td>
<td>88%</td>
<td>35334.9</td>
</tr>
<tr>
<td>72</td>
<td>0.</td>
<td>6.10</td>
<td>97%</td>
<td>38663.9</td>
</tr>
<tr>
<td>73</td>
<td>0.</td>
<td>4.96</td>
<td>84%</td>
<td>33472.9</td>
</tr>
<tr>
<td>74</td>
<td>6.34</td>
<td>4.13</td>
<td>62%</td>
<td>24635.7</td>
</tr>
<tr>
<td>75</td>
<td>0.</td>
<td>3.85</td>
<td>79%</td>
<td>31605.8</td>
</tr>
<tr>
<td>76</td>
<td>0.</td>
<td>2.04</td>
<td>81%</td>
<td>32319.5</td>
</tr>
<tr>
<td>77</td>
<td>0.</td>
<td>3.04</td>
<td>94%</td>
<td>37745.9</td>
</tr>
<tr>
<td>78</td>
<td>0.</td>
<td>4.16</td>
<td>99%</td>
<td>39668.9</td>
</tr>
<tr>
<td>79</td>
<td>0.</td>
<td>4.02</td>
<td>99%</td>
<td>39621.9</td>
</tr>
</tbody>
</table>

*aQuantity of the harvested grain exceeds the bin capacity.

Humidity usually stays low for a long period of time and then goes high as the drying process approaches end of the year. Therefore, if the low humidity period could be maintained longer during the first period, drying action will then take place rapidly throughout the grain bed with a little overdrying occurring in the bottom layer and, after humid weather comes, the moisture profile will be re-distributed through the rewetting process.
Figures 33 and 34 show the moisture profile and quantity of the harvested corn added as well as the position of drying front for the four bins during 1960. The bottom, top and the average moistures are all drawn on the upper portion of graph to reflect their changes with respect to the Julian date. For the first period of time, the top layer moisture changes up and down very rapidly because the rapid drying action occurs at the shallow depth. The moisture of corn at the bottom layer, on the other hand, almost always follows the changing pattern of
FIGURE 33. The moisture profile and the quantity of grain collected in Bin 1 and Bin 2, 1960 (fan power rating=7.5kw)
FIGURE 34. The moisture profile and the quantity of grain collected in Bin 3 and Bin 4, 1960 (fan power rating=7.5kw)
the ambient air condition. When the ambient air is too humid, it tends to rewet the grain in the bottom layer but might keep the top layer drying at the same time. To avoid over-rewetting in the bottom part, humidistat control was used in the model to shut off the drying process when the relative humidity was higher than 80%.

Figures 33 to 34 also show a similar situation in the other three bins. Basically, they all follow the same pattern in the same year. The grain accumulated in bins depends on the quantity of the harvested grain and on how it is distributed. Normally, it takes three or four loadings to complete the whole filling of one bin. According to the controlled filling schedule, this filling operation is decided by the airflow rate or the position of the drying front. Because grain shrinkage was also considered in the model, therefore, the total volume of grain decreased during the drying periods.

Figures 35 to 37 try to relate the changes of weather to the changes of moisture pattern for three typical severe years--1964, 1969 and 1972. Drying is not finished during fall in these years even the airflow rate is increased to a certain limit. All these years have a long period of high relative humidity. The year 1964 is a normal year for the first drying period (Figure 35) but, because it is too humid in the late period, drying cannot be completed in the late fall. The weather of 1969 is better than that of 1972 but the quantity of harvested grain exceeds the bin capacity and prolongs the harvest period. Consequently, even at the time of fall shutdown, the drying front fails to pass through the grain depth. In 1972, however, it does
not have any chance to dry the wet grain down to the desired moisture.

Filling Strategy

A controlled-filling schedule has been described in Figure 15. Although it is decided by the actual airflow in the bin, the drying front in fact is the main indicator for the further filling decision. When the drying front passes through over one half of the total grain layer, the bin is ready for additional loading. Table 15 shows a typical example of the controlled strategy plan performed by this model.

For this strategy, several points can be outlined here beside the principle that has been described in Figure 15.

1. Bins are loaded one by one according to the actual schedule.
2. The load to a bin during a day might come from two or three plots. Therefore, different moisture of corn is expected and mixing of that quantity is required before drying starts.
3. Field working conditions might delay the filling schedule (not shown in this example).

Results of Management Study

Totally, there are five runs for different schemes and different parameters which are coded as in Table 17.

Tables 18 to 22 give the results of drying for run A to run E, using the optimum controlled filling strategy. In most of the years under test drying can be done within 1,000 hours of fan operation except those that require spring finishes.
FIGURE 35. The weather data and related moisture profile versus drying time in 1964 (Bin 1, fan power rating=8.8 kW)
FIGURE 36. The weather data and related moisture profile versus drying time in 1969 (Bin 1, fan power rating=8.8 kW)
FIGURE 37. The weather data and related moisture profile versus drying time in 1972 (Bin 1, fan power rating=8.8 kW)
### TABLE 16. Controlled filling schedule for 1960

<table>
<thead>
<tr>
<th>Date</th>
<th>Harvested Corn</th>
<th>Corn Distributed to Bins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MCHB% Plot no. bu</td>
<td>Bin1 x bu(m/n)</td>
</tr>
<tr>
<td>281-10/7</td>
<td>25.2 5 1876</td>
<td>1136(1136)1/3</td>
</tr>
<tr>
<td>282-10/8</td>
<td>24.6 5 1876</td>
<td>0(1136)1/3</td>
</tr>
<tr>
<td>283-10/9</td>
<td>24.7 4 790</td>
<td>0(1136)1/3</td>
</tr>
<tr>
<td>284-10/10</td>
<td>24.3 4 2068</td>
<td>1136(2271)2/5</td>
</tr>
<tr>
<td>285-10/11</td>
<td>23.8 4 1278</td>
<td>0(2271)2/5</td>
</tr>
<tr>
<td>287-10/12</td>
<td>23.0 3 628</td>
<td>0(2271)3/5</td>
</tr>
<tr>
<td>287-10/13</td>
<td>23.0 3 1402</td>
<td>0(2271)3/5</td>
</tr>
<tr>
<td>288-10/14</td>
<td>22.6 2 527</td>
<td>0(2271)3/5</td>
</tr>
<tr>
<td>289-10/15</td>
<td>22.1 2 1012</td>
<td>1012(4244)5/10</td>
</tr>
<tr>
<td>290-10/16</td>
<td>21.6 1 610</td>
<td>0(4244)6/10</td>
</tr>
<tr>
<td>291-10/17</td>
<td>21.2 1 624</td>
<td>0(4244)7/10</td>
</tr>
<tr>
<td>292-10/18</td>
<td>20.9 8 1160</td>
<td>0(4244)7/10</td>
</tr>
<tr>
<td>293-10/19</td>
<td>20.6 8 1934</td>
<td>1431(6033)</td>
</tr>
<tr>
<td>294-10/20</td>
<td>20.6 7 127</td>
<td>127(6160)7/13</td>
</tr>
<tr>
<td>295-10/21</td>
<td>20.1 6 13</td>
<td>0(6160)7/13</td>
</tr>
<tr>
<td>296-10/22</td>
<td>19.8 6 1824</td>
<td>0(6160)8/14</td>
</tr>
</tbody>
</table>

*a* = Quantity of the harvest corn distributed to that bin that day.

*Y* = Total bushels stored in that bin.

*m* = Total drying layers.

*n* = Total layers for the drying front.
TABLE 17. Code no. for different runs of management study

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Fan power</th>
<th>Scheme no.</th>
<th>Harvest moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8.8 kW</td>
<td>a</td>
<td>26%</td>
</tr>
<tr>
<td>B</td>
<td>8.8 kW</td>
<td>b</td>
<td>26%</td>
</tr>
<tr>
<td>C</td>
<td>13.2 kW</td>
<td>a</td>
<td>26%</td>
</tr>
<tr>
<td>D</td>
<td>13.2 kW</td>
<td>b</td>
<td>26%</td>
</tr>
<tr>
<td>E</td>
<td>13.2 kW</td>
<td>a</td>
<td>24%</td>
</tr>
</tbody>
</table>

^Scheme a: planted half for medium and half for short. Scheme b: planted all for short.

Results of run A under a 8.8 kW fan is shown in Table 18. The fan operation hours range from 480 to 1752 depending on the weather of the individual year.

For run A (Table 18), it takes about two to three weeks, or 19 days to harvest and fill all four bins. This filling period tends to decrease a little for other runs, or, 17 days for run E (Table 22) and 18 days for other combinations (Table 19-Table 21).

There are four years that harvest starts in September (run A). This harvest situation does not change much when a high airflow fan is applied (run C, Table 20), but does change when scheme b is considered (run D, Tables 19 and 21). Planting all with short season corn (scheme b) usually shifts the harvest schedule earlier.

The drying energy is the net energy required to evaporate water in corn from the moisture of the first loading to the final desired moisture. For run A, the specific energy consumption ranges from 299.9
TABLE 18. Controlled-filling drying performance using CORNDRY for run A (fan power rating=8.8 kW)

<table>
<thead>
<tr>
<th>year</th>
<th>Starts</th>
<th>Ends</th>
<th>Days</th>
<th>Starts</th>
<th>Ends</th>
<th>Days</th>
<th>filling Schedule</th>
<th>Drying</th>
<th>Fan Btu/ h</th>
<th>MJ/ h</th>
<th>Deterioration, %</th>
<th>total</th>
<th>Grain MCBW%</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
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<td>10/ 8(282)</td>
<td>10/21</td>
<td>13</td>
<td>11/ 3(308)</td>
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<td>0.072</td>
<td>6813</td>
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<td></td>
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<tr>
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<td>10/26</td>
<td>19</td>
<td>4/24(114)</td>
<td>1776</td>
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<td>1.820</td>
<td>0.063</td>
<td>0.093</td>
<td>7948</td>
<td>25.6-14.0</td>
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<td></td>
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<tr>
<td>62</td>
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<td>10/22</td>
<td>20</td>
<td>11/23(327)</td>
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<td>1.397</td>
<td>0.061</td>
<td>0.096</td>
<td>7282</td>
<td>26.0-14.8</td>
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</tr>
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<td>19</td>
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<td>10</td>
<td>4/ 6(96)</td>
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<td>0.034</td>
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<tr>
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<td>10/27</td>
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</table>

Average 19 1163 571.6 1.330 0.067 0.109

a Btu is calculated from fan energy per pound of water removed.
b Julian date.
c Spring finishes required.
TABLE 19. Controlled-filling drying performance using CORNDRY for run B (fan power rating=8.8 kW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Filling Schedule</th>
<th>Drying</th>
<th>Fan Btu/ha MJ/ha</th>
<th>Deterioration, %</th>
<th>Grain MCWB%</th>
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<tbody>
<tr>
<td></td>
<td>Starts Ends Days</td>
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<td>11/ 3 (308)</td>
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<tr>
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<td>10/26</td>
<td>20</td>
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<td>19</td>
<td>11/ 14 (318)</td>
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</tr>
<tr>
<td>63</td>
<td>10/ 1 (274)</td>
<td>10/17</td>
<td>17</td>
<td>10/28 (301)</td>
<td>672</td>
</tr>
<tr>
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<td>17</td>
<td>11/19 (314)</td>
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<td>13</td>
<td>4/ 9 (99)</td>
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<td>16</td>
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<tr>
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<td>16</td>
<td>11/11 (315)</td>
<td>840</td>
</tr>
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<td>19</td>
<td>4/13 (103)</td>
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</tr>
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<td>10/28</td>
<td>23</td>
<td>4/24 (114)</td>
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</tr>
<tr>
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<td>10/16</td>
<td>24</td>
<td>4/16 (106)</td>
<td>1824</td>
</tr>
<tr>
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<td>19</td>
<td>4/24 (114)</td>
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<td>11/ 6 (310)</td>
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</tr>
<tr>
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<td>18</td>
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</tr>
<tr>
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<td>10/22 (292)</td>
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<td>18</td>
<td>11/ 6 (310)</td>
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<td>10/22</td>
<td>19</td>
<td>10/28 (302)</td>
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</table>

Average 18 1018 558.2 1.298 0.057 0.096

a Btu is calculated from fan energy per pound of water removed.
b Julian date.
c Spring finishes required.

TABLE 19. Controlled-filling drying performance using CORNDRY for run B (fan power rating=8.8 kW)
<table>
<thead>
<tr>
<th>Year</th>
<th>Filling Schedule</th>
<th>Drying Schedule</th>
<th>Fan Starts</th>
<th>Fan Stops</th>
<th>Btu/ Hr</th>
<th>MJ/ Hr</th>
<th>Deterioration, %</th>
<th>Grain MCWB% (init.-Final)</th>
</tr>
</thead>
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<td>10/28(302)</td>
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<td>0.024 0.034</td>
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<td>11/11(315)</td>
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</tr>
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<td>11/10(314)</td>
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<td>7282 26.0-15.3</td>
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<td>10/14 15</td>
<td>10/23(296)</td>
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<td>0.932</td>
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<td>7949 25.7-14.8</td>
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<td>10/25 18</td>
<td>11/ 9(314)</td>
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<td>11/19(323)</td>
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<td>11/10(314)</td>
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<td>10/13 23</td>
<td>10/25(298)</td>
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<td>10/13 23</td>
<td>10/26(299)</td>
<td>864</td>
<td>581.7</td>
<td>1.207</td>
<td>0.037 0.075</td>
<td>9084 25.0-13.7</td>
</tr>
<tr>
<td>78</td>
<td>10/ 1(274)</td>
<td>10/19 19</td>
<td>11/ 3(307)</td>
<td>816</td>
<td>504.3</td>
<td>0.941</td>
<td>0.038 0.061</td>
<td>10220 25.6-13.5</td>
</tr>
<tr>
<td>79</td>
<td>10/ 4(277)</td>
<td>10/16 15</td>
<td>12/16(350)</td>
<td>1272</td>
<td>813.6</td>
<td>1.892</td>
<td>0.059 0.084</td>
<td>9084 25.7-15.4</td>
</tr>
</tbody>
</table>

| Average | 18 | 863 | 640.6 | 1.490 | 0.046 | 0.079 |

a Btu is calculated from fan energy per pound of water removed.
b Julian date.
c Spring finishes required.
TABLE 21. Controlled-filling drying performance using CORNDRY for run D (fan power rating=13.2 kW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Filling Schedule</th>
<th>Drying Schedule</th>
<th>Fan Power</th>
<th>Btu/(\text{HJ/}\text{D})</th>
<th>Deterioration, %</th>
<th>Grain MC W%</th>
<th>Total Bu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starts</td>
<td>Ends</td>
<td>Days</td>
<td>Fan</td>
<td>Btu</td>
<td>MJ/Kg</td>
<td>Ave.</td>
</tr>
<tr>
<td>60</td>
<td>10/7</td>
<td>10/20</td>
<td>14</td>
<td>11/3</td>
<td>692</td>
<td>444.0</td>
<td>1.033</td>
</tr>
<tr>
<td>61</td>
<td>10/7</td>
<td>10/26</td>
<td>20</td>
<td>11/3</td>
<td>672</td>
<td>466.1</td>
<td>1.084</td>
</tr>
<tr>
<td>62</td>
<td>10/3</td>
<td>10/22</td>
<td>20</td>
<td>11/10</td>
<td>936</td>
<td>768.4</td>
<td>1.787</td>
</tr>
<tr>
<td>63</td>
<td>9/29</td>
<td>10/13</td>
<td>15</td>
<td>10/25</td>
<td>648</td>
<td>411.6</td>
<td>0.927</td>
</tr>
<tr>
<td>64</td>
<td>10/4</td>
<td>10/19</td>
<td>16</td>
<td>10/26</td>
<td>600</td>
<td>430.4</td>
<td>1.001</td>
</tr>
<tr>
<td>65</td>
<td>10/26/299</td>
<td>11/7</td>
<td>13</td>
<td>4/9</td>
<td>991</td>
<td>709.0</td>
<td>1.790</td>
</tr>
<tr>
<td>66</td>
<td>10/9</td>
<td>10/22</td>
<td>15</td>
<td>11/3</td>
<td>600</td>
<td>499.2</td>
<td>1.161</td>
</tr>
<tr>
<td>67</td>
<td>10/7</td>
<td>10/22</td>
<td>16</td>
<td>11/11</td>
<td>624</td>
<td>571.4</td>
<td>1.329</td>
</tr>
<tr>
<td>68</td>
<td>10/8</td>
<td>10/26</td>
<td>19</td>
<td>11/15</td>
<td>864</td>
<td>914.3</td>
<td>2.127</td>
</tr>
<tr>
<td>69</td>
<td>10/4</td>
<td>10/27</td>
<td>24</td>
<td>4/11</td>
<td>1512</td>
<td>731.5</td>
<td>1.753</td>
</tr>
<tr>
<td>70</td>
<td>9/23</td>
<td>10/16</td>
<td>24</td>
<td>4/11</td>
<td>1728</td>
<td>753.7</td>
<td>1.753</td>
</tr>
<tr>
<td>71</td>
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<td>10/13</td>
<td>23</td>
<td>10/23</td>
<td>792</td>
<td>521.9</td>
<td>1.214</td>
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<tr>
<td>72</td>
<td>10/7</td>
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<td>18</td>
<td>4/9</td>
<td>1680</td>
<td>991.3</td>
<td>2.306</td>
</tr>
<tr>
<td>73</td>
<td>10/1</td>
<td>10/17</td>
<td>17</td>
<td>10/31</td>
<td>744</td>
<td>496.5</td>
<td>1.155</td>
</tr>
<tr>
<td>74</td>
<td>10/3</td>
<td>10/19</td>
<td>17</td>
<td>10/23</td>
<td>504</td>
<td>349.9</td>
<td>0.814</td>
</tr>
<tr>
<td>75</td>
<td>9/29/272</td>
<td>10/16</td>
<td>18</td>
<td>10/22</td>
<td>576</td>
<td>395.5</td>
<td>0.920</td>
</tr>
<tr>
<td>76</td>
<td>9/20/264</td>
<td>10/4</td>
<td>15</td>
<td>10/6</td>
<td>408</td>
<td>396.7</td>
<td>0.927</td>
</tr>
<tr>
<td>77</td>
<td>9/21/264</td>
<td>10/6</td>
<td>16</td>
<td>10/19/292</td>
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<td>492.5</td>
<td>1.146</td>
</tr>
<tr>
<td>78</td>
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<td>10/18</td>
<td>18</td>
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<td>744</td>
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<td>10/5</td>
<td>10/21</td>
<td>18</td>
<td>12/3</td>
<td>1104</td>
<td>670.2</td>
<td>1.559</td>
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</table>

Average: 18

\[\text{Btu is calculated from fan energy per pound of water removed.}\]
\[\text{b Julian date.}\]
\[\text{c Spring finishes required.}\]
<table>
<thead>
<tr>
<th>Year</th>
<th>Filling Schedule</th>
<th>Drying</th>
<th>Fan Btu(^{a})</th>
<th>Deterioration,%</th>
<th>Grain MCWB%</th>
<th>Total Grain MCWB%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starts</td>
<td>Ends</td>
<td>Days</td>
<td>Hours</td>
<td>lb</td>
<td>kg</td>
</tr>
<tr>
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<td>10/10(284)</td>
<td>10/20</td>
<td>11</td>
<td>11/3(308)</td>
<td>600</td>
<td>586.1</td>
</tr>
<tr>
<td>61</td>
<td>10/17(290)</td>
<td>11/3</td>
<td>14</td>
<td>11/15(319)</td>
<td>720</td>
<td>813.9</td>
</tr>
<tr>
<td>62</td>
<td>10/12(285)</td>
<td>10/26</td>
<td>10</td>
<td>11/21(325)</td>
<td>960</td>
<td>775.4</td>
</tr>
<tr>
<td>63</td>
<td>10/4(277)</td>
<td>10/19</td>
<td>16</td>
<td>11/1(305)</td>
<td>696</td>
<td>132.7</td>
</tr>
<tr>
<td>64</td>
<td>10/14(286)</td>
<td>10/27</td>
<td>13</td>
<td>11/13(318)</td>
<td>744</td>
<td>596.3</td>
</tr>
<tr>
<td>65</td>
<td>11/4(308)</td>
<td>12/1</td>
<td>28</td>
<td>4/15(105)</td>
<td>888</td>
<td>1650.2</td>
</tr>
<tr>
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<td>10/28</td>
<td>17</td>
<td>11/29(333)</td>
<td>888</td>
<td>939.4</td>
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<tr>
<td>67</td>
<td>10/18(291)</td>
<td>10/29</td>
<td>12</td>
<td>11/18(322)</td>
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<td>13</td>
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<td>18</td>
<td>4/9(99)</td>
<td>1464</td>
<td>1560.2</td>
</tr>
<tr>
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<td>9/27(270)</td>
<td>10/14</td>
<td>18</td>
<td>10/27(300)</td>
<td>744</td>
<td>575.2</td>
</tr>
<tr>
<td>72</td>
<td>10/15(289)</td>
<td>11/10</td>
<td>27</td>
<td>4/18(108)</td>
<td>1536</td>
<td>1076.5</td>
</tr>
<tr>
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<td>11/3</td>
<td>20</td>
<td>12/11(345)</td>
<td>960</td>
<td>856.2</td>
</tr>
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<td>10/9(282)</td>
<td>10/21</td>
<td>13</td>
<td>10/29(302)</td>
<td>504</td>
<td>469.7</td>
</tr>
<tr>
<td>75</td>
<td>10/5(278)</td>
<td>10/15</td>
<td>11</td>
<td>10/21(294)</td>
<td>408</td>
<td>374.6</td>
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<td>9/20(264)</td>
<td>10/4</td>
<td>15</td>
<td>6/28(60)</td>
<td>408</td>
<td>406.0</td>
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<tr>
<td>77</td>
<td>9/26(269)</td>
<td>10/17</td>
<td>22</td>
<td>10/28(301)</td>
<td>792</td>
<td>553.7</td>
</tr>
<tr>
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<td>10/5(278)</td>
<td>10/23</td>
<td>19</td>
<td>11/4(308)</td>
<td>744</td>
<td>438.4</td>
</tr>
<tr>
<td>79</td>
<td>10/7(280)</td>
<td>10/24</td>
<td>18</td>
<td>12/15(349)</td>
<td>1176</td>
<td>837.7</td>
</tr>
</tbody>
</table>

Average 17 880 795.1 1.850 0.056 0.109

\(^{a}\) Btu is calculated from fan energy per pound of water removed.
\(^{b}\) Julian date.
\(^{c}\) Spring finishes required.
to 1210.7 Btu/lb of water removed. The years that require spring finishes usually need more energy to complete drying because the fan will take longer to operate. A typical example of poor year is 1965, in which the corn has been harvested very late, the yield was low, and a spring finish was also required. Eventually, it consumes the highest drying energy of all.

Normally, the grain quality is good using the optimum controlled filling strategy. Taking run A (Table 18) as an example, the maximum deterioration is 0.22%, which occurs in 1969. It is lower than those not using this strategy. The deterioration rate is also lower than those reported by Van Ee (1979). The reason of this difference might be the lower temperature at Sioux Falls as compared to that of Des Moines.

Table 23 summarizes the average results of Table 18 to Table 22 for comparisons. For the scheme a, with lower fan power, nine out of twenty years required spring finishes. However, all the spring finish drying can be dried down safely without damage to corn quality.

Use of a higher airflow fan (run C) will decrease the number of spring finishes to four, which, in our study, is the lowest number of finishes we can cut down to by using any combinations of management (from run A to run E).

Planting 300 acres with all short season corn (run B and run D) is another way to decrease the number of spring finishes. The results show six for the 8.8 kW fan and four for the 13.2 kW fan in this run. However, for the severe years like 1965, 1969, 1970 and 1972, supplemental heat is still required to avoid spring finishes.
TABLE 23. Comparisons of results for different management schemes

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Moisture %MCWB</th>
<th>Fan power, kW</th>
<th>Spring finishes</th>
<th>No. of failures</th>
<th>Max. deterioration, %</th>
<th>Average, %</th>
<th>Fan hours</th>
<th>Drying energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>D</td>
<td>A</td>
<td>C</td>
<td>E</td>
<td></td>
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<tr>
<td>26</td>
<td>26</td>
<td>8.8</td>
<td>6</td>
<td>9</td>
<td>0.109</td>
<td>0.067</td>
<td>1017.6</td>
<td>558.2 Btu/lb</td>
</tr>
<tr>
<td>26</td>
<td>26</td>
<td>13.2</td>
<td>4</td>
<td>4</td>
<td>0.079</td>
<td>0.046</td>
<td>855.4</td>
<td>661.1 Btu/lb</td>
</tr>
<tr>
<td>26</td>
<td>26</td>
<td>13.2</td>
<td>9</td>
<td>4</td>
<td>0.096</td>
<td>0.057</td>
<td>1162.8</td>
<td>571.6 Btu/lb</td>
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<tr>
<td>24</td>
<td>26</td>
<td>13.2</td>
<td>4</td>
<td>5</td>
<td>0.076</td>
<td>0.044</td>
<td>826.8</td>
<td>1.298 MJ/kg</td>
</tr>
<tr>
<td>24</td>
<td>26</td>
<td>13.2</td>
<td>5</td>
<td>1</td>
<td>0.109</td>
<td>0.056</td>
<td>879.6</td>
<td>1.433 MJ/kg</td>
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</tbody>
</table>

Harvest of corn at a lower moisture content—24 %MCWB—is another possibility to improve the results (Table 22). From the results of run E, five spring finishes are required when the moisture of harvested corn is below 24%. In this case, however, there is a danger of increasing the deterioration rate during drying. One year of failures was observed in this arrangement (year 1965).

For an optimum controlled strategy, best results occur as the harvest moisture is set at 26%. This is particularly true when the weather is usually humid during the late drying period. On the same fan power condition, the late harvest schedule (24%) takes more operation time and more specific drying energy for the same area. However, this late schedule has been used by Van Ee and Kline (1979b) for the central
Iowa condition. In their report, they found that only two out of eighteen years needed spring finishes (1958-1975). In this study, comparisons of run C (Table 20) and run E (Table 22) show that, in most years, the late harvest schedule does have shorter fan operation hours than the early one. This means that, in this area, the late harvest schedule is still applicable when the weather is good. Therefore, harvest at moistures from 24% to 26% using the optimum controlled filling strategy is also recommended.
SUMMARY

CORNSIM and FALDRY are two models which predict the corn growth, harvesting and drying for a medium-size farm. In this study, both models are combined into the CORNDRY model and run together to obtain similar results for the condition of northwestern Iowa.

A FLDAY model was also developed to predict the field workdays from weather data. This model was based on a soil budget by considering a soil profile of one foot depth. Validation of the model was done by using the observed available workdays as reported by the Iowa Crop and Livestock Reporting Service. The correlation can reach 0.923.

The CORNDRY model, after incorporating revised CORNSIM and FALDRY models, has a capability of handling all previous functions at the same time. Simulation of corn production, harvesting, bin handling and drying then becomes a one-pass run. Besides, most of the important parameters such as corn yield, silking date, are designed as input to the model so that model can predict the corn production system for any location. The drying model, inside the CORNDRY, was modified by incorporating Misra and Brooker's thin layer drying equation to cut down the computing time.

Validation of the layer drying strategy using this drying model has been conducted on two actual bins located at Farnhamville and Glidden, Iowa. Weather data of Des Moines and Sioux Falls, in 1979 were used to fit the model and to predict the moisture profile for these two bins at different drying periods. Agreement of the predicted and observed moisture profiles is satisfactory.
For the management study, an optimum controlled-filling strategy was applied on a 300-acre farm. Weather data of Sioux Falls from 1960 to 1979 were used as the input of the model accompanied by the fieldwork data generated from the developed FLDAY model. The CORNDRY model was then used to predict the results of a corn production and drying system for a medium-size farm (300 acres) with a combine and at least four drying bins.

To cope with the actual situation, this 300 acre field was arranged into two schemes for combinations of corn varieties planted. The first scheme assumed that half of the field was planted with medium and another half with short season corn; while the second assumed that all fields were planted with the short season corn. There were also two fan power levels assumed in this study—8.8 kW and 13.2 kW, which are the most common sizes in use in Iowa.

The controlled filling schedule was applied on four 30-ft bins with a holding capacity of 10,000 bushels each during harvest. The harvested corn was loaded into the bins according to the progress of the drying front in the bins.

For a high airflow fan (13.2 kW), in sixteen out of twenty years drying of the harvested corn can be finished during fall by about 830 hours of operation. Use of a low fan power (8.8 kW) will decrease the specific drying energy consumption from 660 Btu/lb of water removed to 560 Btu/lb of water removed, but will extend the time of fan operation to about 1,100 hours.

The number of spring finishes also increased as the fan power
decreased. According to the results, nine spring finishes were required if the 8.8 kW fan was used, and only four were needed for the 13.2 kW fan. Results on the number of spring finishes were very close for both field schemes but the scheme with only short season corn planted had fewer spring finishes using a low fan power.

In general, the grain maintained a good quality after drying is complete, using the controlled filling strategy. In most years, the deterioration rate is lower than 0.1%.

For better results in northwestern Iowa, the controlled-filling strategy is then recommended and high fan power can be used to avoid more spring finishes of drying.
CONCLUSIONS

1. The FLDAY model can be employed to predict field workdays for the whole year satisfactorily using weather records. The pan evaporation is used as a main parameter in the model but can be replaced by an estimating subroutine if this information is not available.

2. The CORNDRY model can successfully simulate the corn growth and harvesting process and can predict the drying results in a run.

3. For northwestern Iowa, using controlled filling strategy, most bins can be filled within about 18 days, depending on the weather records. The whole drying procedure requires about 1,160 hours of fan operation for the 8.8 kW fan and 830 hours for 13.2 kW fan. A high powered fan will decrease the hours of fan operation but will increase the energy consumption.

4. For the four-bin drying system, corn yield of a 300 acre farm will fill the bin to 70% full. For one out of twenty years the total corn yield exceeds this capacity, however.

5. Results of different management studies for northwestern Iowa for the past twenty years (1960-1979) show that, of 300 acres half planted with medium and half with short season corn (scheme a), the harvested corn can be dried completely in fall for fourteen years if an 8.8 kW fan is used, or, six of spring finishes for complete drying are required. The number
of spring finishes will decrease to four if a high airflow fan (13.2 kW) is used.

6. The grain quality is good (dry-matter loss < 0.1%) after drying is completed even when a spring finishes is required.
SUGGESTIONS FOR FURTHER RESEARCH

1. Develop a similar computer program that can be run on a microcomputer such as Apple II. With weather data input on a daily basis, a farmer can follow the present drying system and know exactly the drying status without a need of frequently checking the bin.

2. Build up more drying program modules that can take care of other situations such as solar desiccant drying, biomass and stirring drying applications.

3. Conduct the same type of analysis on the southern part of Iowa and other areas.

4. Conduct further field tests on the controlled filling strategy.

5. Conduct an economic analysis of the controlled filling strategy.

6. Simulate soybean production and harvesting systems or systems rotated with corn and soybeans, using the controlled filling strategy.

7. Combine this program with the yield prediction model.
BIBLIOGRAPHY


Muller, R. E., R. M. Peart, and G. H. Foster. 1980 Analysis of combination corn drying systems. ASAE Paper No. 80-3018.


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Appreciation is also expressed to the Department of Agricultural Engineering for use of their facilities.

Finally, sincere gratitude to his family and his wife, Shelley, for their patience and assistance.
APPENDIX A. DATA INPUT FORMATS

TABLE 24. Data input format for the FLDAY model

<table>
<thead>
<tr>
<th>Variables</th>
<th>columns</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IYR</td>
<td>1-2</td>
<td>I2</td>
<td>The starting year (last two digits).</td>
</tr>
<tr>
<td>JYR</td>
<td>3-4</td>
<td>I2</td>
<td>The end year (last two digits).</td>
</tr>
</tbody>
</table>
| ICLAY     | 5       | I1     | Types of clay: 
|           |         |        | 1 = clay; |
|           |         |        | 2 = clay loam; |
|           |         |        | 3 = sandy loam. |
| FC(3)     | 7-18    | 3F4.2  | Field capacity of three layers, in. |
| DRS       | 19-20   | F2.1   | Drainage coefficient. |
| DUP       | 21-22   | F2.1   | Diffusion coefficient. |
| R1        | 23-26   | F4.2   | Ratio of surface evaporation and open pan evaporation before June 7. |
| R2        | 27-30   | F4.2   | Ratio of surface evaporation and open pan evaporation after June 7. |
| KC        | 31-32   | I2     | Control for using the ESPAN subroutine 
|           |         |        | 0 = default; |
|           |         |        | 1 = using ESPAN only. |
| JC        | 33-34   | I2     | Output control: 
|           |         |        | 0 = hard copy; |
|           |         |        | 1 = on file. |
| IC        | 35-36   | I2     | Corrections of zero observations 
<p>|           |         |        | 0 = default. |
|           |         |        | 1 = corrected for observations of zero field workday/week. |</p>
<table>
<thead>
<tr>
<th>Variables</th>
<th>columns</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDAY(4)</td>
<td>1-9</td>
<td>312,13</td>
<td>Year/month/day, Julian date.</td>
</tr>
<tr>
<td>ITEM(4)</td>
<td>10-21</td>
<td>413</td>
<td>Max., min., average, and dew point temperature, °F.</td>
</tr>
<tr>
<td>WB</td>
<td>22-24</td>
<td>F3.0</td>
<td>Wet-bulb temperature, °F.</td>
</tr>
<tr>
<td>WBBDPERS</td>
<td>25-27</td>
<td>F3.0</td>
<td>Average wet-bulb depression, °F.</td>
</tr>
<tr>
<td>RH</td>
<td>28-30</td>
<td>F3.0</td>
<td>Relative humidity, %.</td>
</tr>
<tr>
<td>IFREZ</td>
<td>31</td>
<td>I1</td>
<td>1 = min. dry bulb temp. ≤ 28°F. 0 = min. dry bulb temp. &gt; 28 °F.</td>
</tr>
<tr>
<td>EQM</td>
<td>33-37</td>
<td>F5.4</td>
<td>Equilibrium moisture content of corn in the field, decimal.</td>
</tr>
<tr>
<td>GDU</td>
<td>38-40</td>
<td>F3.0</td>
<td>Growing degree units per day.</td>
</tr>
<tr>
<td>CUMGDU</td>
<td>41-45</td>
<td>F5.0</td>
<td>Cumulative GDU for the year.</td>
</tr>
<tr>
<td>ISNOW</td>
<td>46-50</td>
<td>I4</td>
<td>Snow on the ground, in.</td>
</tr>
<tr>
<td>RAIN</td>
<td>51-54</td>
<td>F4.2</td>
<td>Precipitation, in.</td>
</tr>
<tr>
<td>IGO</td>
<td>56</td>
<td>I1</td>
<td>0 = field is not trafficable. 1 = available field workday.</td>
</tr>
<tr>
<td>PAN</td>
<td>59-62</td>
<td>F4.2</td>
<td>Pan evaporation, in.</td>
</tr>
</tbody>
</table>
TABLE 26. Input format of base management for the CORNDRY model

<table>
<thead>
<tr>
<th>Card Variables</th>
<th>Column Numbers</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>no.</td>
<td>umns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>M&amp;INC</td>
<td>1</td>
<td>I1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0 = default for new CORNDRY.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 = for CORNSIM only.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 = for FALDRY only (drying).</td>
</tr>
<tr>
<td>1</td>
<td>PLACE</td>
<td>2-17</td>
<td>4A4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Name of location.</td>
</tr>
<tr>
<td>2</td>
<td>MINFLD</td>
<td>1-4</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Min. no. of available field days needed before planting begins.</td>
</tr>
<tr>
<td>3</td>
<td>JPLTST(5,2)</td>
<td>1-20</td>
<td>5I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max. of 5 sets of planting strategy (acreage, and corn varieties code--</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 = long season; 2 = medium season; 3 = short season corn).</td>
</tr>
<tr>
<td>4</td>
<td>IPLYDRY(5)</td>
<td>1-20</td>
<td>5I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Julian dates for planting--starting date, last dates to plant full, medium, and short season corn.</td>
</tr>
<tr>
<td>5</td>
<td>IHRPDY(6,2)</td>
<td>1-48</td>
<td>12I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max. of 6 sets of work time strategy—Julian date, and hours of available field time per day.</td>
</tr>
<tr>
<td>6</td>
<td>IHARDY</td>
<td>1-8</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Last possible Julian day to begin harvest regardless of grain moisture.</td>
</tr>
<tr>
<td>6</td>
<td>IFDY</td>
<td>5-8</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>First Julian day to begin harvest.</td>
</tr>
<tr>
<td>7</td>
<td>HARMST</td>
<td>1-5</td>
<td>F5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grain moisture that begins harvest.</td>
</tr>
<tr>
<td>8</td>
<td>IYRSTR</td>
<td>1-4</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The starting year (last two digit.)</td>
</tr>
<tr>
<td>8</td>
<td>IYRSTP</td>
<td>5-6</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The end year (last two digit).</td>
</tr>
<tr>
<td>9</td>
<td>PLTRAT</td>
<td>1-5</td>
<td>F5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Planting rate, ac/h.</td>
</tr>
<tr>
<td>9</td>
<td>HARRAT(2)</td>
<td>6-15</td>
<td>2F5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max. of harvest rate, in ac/h and bu/h respectively.</td>
</tr>
<tr>
<td>10</td>
<td>YLDPOT(20)</td>
<td>1-50</td>
<td>10F5.0</td>
</tr>
<tr>
<td>11</td>
<td>YLDPOT(20)</td>
<td>1-50</td>
<td>10F5.0</td>
</tr>
<tr>
<td>12</td>
<td>ISLKDY(3)</td>
<td>1-12</td>
<td>3I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Days from silking to dry-down stage for full, medium and short corn.</td>
</tr>
<tr>
<td>13</td>
<td>IPRINT</td>
<td>1-4</td>
<td>I4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Output controls--0-3 CORNSIM data. 4-SDO, HC and FLa; 5-DDO, HC &amp; FL 6-SDO, FL; 7-DDO, HC; 8-10b--same as 5 but reports every (IPRINT-7) days.</td>
</tr>
</tbody>
</table>

aSDO=simple drying output; DDO=detailed drying output; HC=hard copy on printer; FL=output stored in file BIN1-BIN4.
bAll versions will print out grain loading schedule, final, fall or spring shutdown summary reports on hard copy; For version 8, weekly summary reported will be printed also.
### TABLE 27. Data input format for the CORNDRY model (Bin data)

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Variables</th>
<th>Columns</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>MB</td>
<td>2</td>
<td>I1</td>
<td>Total number of bins in use.</td>
</tr>
</tbody>
</table>
| 14       | MSTO      | 3-4     | I2     | 0 = default, no aeration during winter.  
1 = daily calculation on deterioration rate, grain temperature for winter.  
2 = aeration as conditions meet the criteria during winter period. |
| 14       | MODE      | 5-6     | I2     | Controls for different drying modes.  
1- Thompson's equilibrium model.  
2- Combination models.  
3- Morey's model (Misra & Brooker eq.)  
4- Pierce and Thompson's model.  
5- Misra & Brooker's thin layer eq. |
| 14       | IWET      | 7-8     | I2     | Controls for rewetting process,  
0 = no absorption assumed.  
1 = use Morey's model.  
2 = use Misra and Brooker's equation.  
3 = use desorption equation only. |
| 15       | BCFM      | 1-6     | F6.4   | Broken corn and foreign material, decimal |
| 15       | GHAV      | 7-12    | F6.1   | Criterion of ave. mc for fall shutdown, % |
| 15       | GMAX      | 13-18   | F6.1   | Criterion of max. mc for fall shutdown, % |
| 15       | TRANS     | 19-24   | F6.1   | Grain handling rate, bu/h. |
| 15       | TMOFF     | 25-30   | F6.1   | Time interval for aeration in winter, hr. |
| 15       | CAR       | 31-36   | F6.1   | Min. load harvested a day, bu/day. |
| 15       | XIN       | 37-42   | F6.1   | Max. quantity of harvested to distribute to a bin a time, 0 = default;  
< 10 in ft.; >= 10 in bushels. |
| 15       | IC        | 43-44   | I2     | Control code for different filling method. (see Table 29). |
| 15       | MAXLAY    | 45-46   | I2     | Max. number of layers in bins for drying (max. = 20 layers). |
| 15       | TLOW      | 47-51   | F5.1   | Min. air temp. that shuts off drying. |
| 15       | TDTR      | 52-56   | F5.1   | Min. grain temperature that allows aeration in process in winter. °F. |
| 15       | RHOFF     | 57-61   | F5.1   | Max. relative humidity that allows aeration and drying to continue, %. |
| 15       | JRHDY     | 62-64   | I3     | The date that humidistat control starts. |
| 16       | BINDA(i)  | 2-6     | F5.2   | Bin diameter, ft. |
| 16       | BINM(i)   | 7-11    | F5.2   | Bin height, ft. |
| 16       | FANKW(i)  | 12-15   | F4.1   | Fan power rating, kW. |
| 16       | SUPHT(i)  | 16-20   | F5.2   | Supplemental heat, >100 in Btu/min.; ≤100 in °F. |
### TABLE 27. (Continued)

<table>
<thead>
<tr>
<th>Card no.</th>
<th>Variables</th>
<th>Columns</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>FANCH(i,2,10)</td>
<td>21-70</td>
<td>10F5.1</td>
<td>Fan data, static pressure, in. of water.</td>
</tr>
<tr>
<td>17</td>
<td>FANCH(i,2,10)</td>
<td>1-50</td>
<td>10F5.0</td>
<td>Fan data, airflow rate, cfm.</td>
</tr>
</tbody>
</table>

\( a \): Bin number, \( i=1 \) to MB.
For the fan data input, two cards per bin are needed.

### TABLE 28. Input format of weather data for the FALDRY mode only (MAINC=2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Columns</th>
<th>Format</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>KCARD</td>
<td>1</td>
<td>I1</td>
<td>No. of loads of harvested grain that day (one card for each load).</td>
</tr>
<tr>
<td>KFL</td>
<td>2-4</td>
<td>I3</td>
<td>No. of following days that will use the same information as this card.</td>
</tr>
<tr>
<td>IDAY(4)</td>
<td>5-12</td>
<td>3I2,I3</td>
<td>Year/month/day, Julian date.</td>
</tr>
<tr>
<td>DELO</td>
<td>14-15</td>
<td>F2.0</td>
<td>Time interval for each card, hours.</td>
</tr>
<tr>
<td>DB</td>
<td>16-18</td>
<td>F3.1</td>
<td>Air temperature, °F.</td>
</tr>
<tr>
<td>RH</td>
<td>19-21</td>
<td>F3.1</td>
<td>Relative humidity, %</td>
</tr>
<tr>
<td>NB</td>
<td>23</td>
<td>I1</td>
<td>Bin number to be loaded to.</td>
</tr>
<tr>
<td>HGHC</td>
<td>25-27</td>
<td>F3.1</td>
<td>The moisture of harvested grain, %</td>
</tr>
<tr>
<td>GIN</td>
<td>29-34</td>
<td>F6.0</td>
<td>Quantity of grain harvested, bu.</td>
</tr>
</tbody>
</table>
TABLE 29. Controls of loading schedule to bins

<table>
<thead>
<tr>
<th>IC code</th>
<th>Functions</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Controlled-filling strategy</td>
<td>Quantity of grain controlled by program itself.</td>
</tr>
<tr>
<td>2</td>
<td>Controlled-filling</td>
<td>Max. of 4 ft deep per loading.</td>
</tr>
<tr>
<td>3</td>
<td>Layer-filling, drying front passes through grain depth before additional loading.</td>
<td>Load 4 ft for the 1st time, and 2 ft deep for others.</td>
</tr>
<tr>
<td>4</td>
<td>Layer-filling daily</td>
<td>2 ft or XIN(^a) quantity per load.</td>
</tr>
<tr>
<td>5</td>
<td>Single filling</td>
<td>XIN bu per load.</td>
</tr>
<tr>
<td>6</td>
<td>Intermittent layer loading</td>
<td>2 ft or XIN bu per load.</td>
</tr>
</tbody>
</table>

\(^a\)XIN is the quantity specified by the user.
APPENDIX B. DATA OUTPUT FORMS

DATA INPUT FOR A TYPICAL N-W IOWA FARM SIMULATION

YEAR RANGE: STARTING WITH THE 1960 PRODUCTION SEASON
ENDING WITH THE 1960 PRODUCTION SEASON

REstrictions on planting date:
1. First possible day to plant corn: 116
2. Last day to plant long season corn: 134
3. Last day to plant medium season corn: 148
4. Last day to plant short season corn: 155
5. Minimum good spring field days before planting: 15
6. Planting rate (acres per hour): 5.00

Planting strategy: (maximum 5 sets)
- Number of acres: 150 150 0 0 0
- Variety of corn: med shrt

Time available per day for field operations: (maximum 6 sets)
- Julian date: 92 121 135 170 0 0
- Hour per day: 7 8 9 8 0 0

Restrictions on harvesting:
1. Harvest will begin on Julian date 263, and moisture below 24.0% MCWB.
2. Harvest will begin regardless of moisture on Julian date 305.
3. Harvest rate is the lesser of 2.50 acres per hour or 300.00 bushel per hour.

Potential yield, bu./acre (1960-1979):
- 107.2 106.9 111.7 116.7 114.1 85.2 106.9 101.9 95.7 154.2
- 109.2 125.4 140.0 121.3 96.9 120.1 115.3 133.8 141.3 141.2

- Heating units: long—1420; medium—1320; short—1250.
- Silking days: long—22; medium—22; short—22

Output options: print 5 main control 0

Program developed by: G. R. VaneE
Remodelled by: D. S. Fong

FIGURE 38. An example output of title page for the CORNDRY model (base management)
THE AERATION PROCESS DURING STORAGE OR WINTER MONTH IS DETERMINED BY FARMERS.
ALL GRAIN TEMPERATURE AND MOISTURE ARE ASSUMED THE SAME AS THE TIME BINS ARE SHUT OFF.
THE BIN FILLING STRATEGY IS: (CODE= 16031)
CONTROLLED FILLING ACCORDING TO THE DRYING FRONT, 4 BINS USED.

FIGURE 39. An example output of title page for the CORNDRY model (Bin data)
FIGURE 40. An example output of corn dry-down in the field
**HARVEST 1355 BU FROM NO. 6 FIELD TO BIN NO.: 1) 0 BU. 2) 847 BU. 3) 308 BU. 4) 0 BU.**

**MOISTURE: 21.0% LOADING TIME: 0 MIN 33 MIN 12 MIN 0 MIN**

**GRAIN TEMP: 51.0 F TOTAL BU. IN BIN: 4542 BU. 4542 BU. 2579 BU. 2271 BU.**

**HARVEST 637 BU FROM NO. 4 FIELD TO BIN NO.: 1) 0 BU. 2) 0 BU. 3) 637 BU. 4) 0 BU.**

**MOISTURE: 21.4% LOADING TIME: 0 MIN 0 MIN 25 MIN 0 MIN**

**GRAIN TEMP: 51.0 F TOTAL BU. IN BIN: 4542 BU. 4542 BU. 3216 BU. 2271 BU.**

**DATE: 60/10/17 BIN 1 ORYFRNT 7 FAN 2 BUSHEL 066.5 CFM/BU 4.4 CFM/SF 26.24 IN.W. 3.13 FRESH AIR: T= 48.0F RH=50.0%**

**AVERAGE: MCCB=15.3% MCDB=18.1% TEMP=48.2F DTR=0.0264 (INLET AIR: RH=45.6% T= 50.0F H=0.0035)**

<table>
<thead>
<tr>
<th>LAYER NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPTH FT.</td>
<td>0.74</td>
<td>1.58</td>
<td>2.23</td>
<td>3.00</td>
<td>3.82</td>
<td>4.62</td>
<td>5.43</td>
<td>6.25</td>
<td>7.10</td>
<td>7.16</td>
</tr>
<tr>
<td>GRAIN T.</td>
<td>50.4</td>
<td>50.2</td>
<td>50.0</td>
<td>49.7</td>
<td>49.1</td>
<td>48.3</td>
<td>47.1</td>
<td>45.5</td>
<td>43.9</td>
<td>43.8</td>
</tr>
<tr>
<td>MCCB %</td>
<td>12.81</td>
<td>13.09</td>
<td>13.47</td>
<td>13.91</td>
<td>14.82</td>
<td>15.60</td>
<td>16.71</td>
<td>17.87</td>
<td>18.95</td>
<td>20.10</td>
</tr>
<tr>
<td>REL HUM</td>
<td>0.663</td>
<td>0.472</td>
<td>0.485</td>
<td>0.501</td>
<td>0.529</td>
<td>0.573</td>
<td>0.659</td>
<td>0.762</td>
<td>0.851</td>
<td>0.894</td>
</tr>
<tr>
<td>ABS HUM</td>
<td>0.00360</td>
<td>0.00360</td>
<td>0.00370</td>
<td>0.00370</td>
<td>0.00390</td>
<td>0.00410</td>
<td>0.00430</td>
<td>0.00470</td>
<td>0.00510</td>
<td>0.00510</td>
</tr>
</tbody>
</table>

**DATE: 60/10/17 BIN 2 DRYFRNT 6 FAN 2 BUSHEL 4131.8 CFM/BU 4.4 CFM/SF 26.11 IN.W. 3.15 FRESH AIR: T= 48.0F RH=50.0%**

**AVERAGE: MCCB=15.9% MCDB=18.9% TEMP=47.9F DTR=0.0167 (INLET AIR: RH=45.5% T= 50.0F H=0.0035)**

<table>
<thead>
<tr>
<th>LAYER NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPTH FT.</td>
<td>0.75</td>
<td>1.50</td>
<td>2.28</td>
<td>3.04</td>
<td>3.87</td>
<td>4.69</td>
<td>5.51</td>
<td>6.36</td>
<td>7.22</td>
<td>7.28</td>
</tr>
<tr>
<td>GRAIN T.</td>
<td>50.3</td>
<td>50.1</td>
<td>49.8</td>
<td>49.5</td>
<td>48.6</td>
<td>47.4</td>
<td>46.4</td>
<td>45.6</td>
<td>44.7</td>
<td>44.7</td>
</tr>
<tr>
<td>REL HUM</td>
<td>0.465</td>
<td>0.476</td>
<td>0.491</td>
<td>0.510</td>
<td>0.557</td>
<td>0.626</td>
<td>0.737</td>
<td>0.855</td>
<td>0.873</td>
<td>0.876</td>
</tr>
<tr>
<td>ABS HUM</td>
<td>0.00360</td>
<td>0.00360</td>
<td>0.00370</td>
<td>0.00380</td>
<td>0.00400</td>
<td>0.00430</td>
<td>0.00470</td>
<td>0.00520</td>
<td>0.00540</td>
<td>0.00540</td>
</tr>
</tbody>
</table>

**DATE: 60/10/17 BIN 3 DRYFRNT 6 FAN 2 BUSHEL 2895.2 CFM/BU 4.9 CFM/SF 26.67 IN.W. 2.73 FRESH AIR: T= 48.0F RH=50.0%**

**AVERAGE: MCCB=15.9% MCDB=18.6% TEMP=45.5F DTR=0.0156 (INLET AIR: RH=45.9% T= 50.0F H=0.0035)**

<table>
<thead>
<tr>
<th>LAYER NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPTH FT.</td>
<td>0.75</td>
<td>1.51</td>
<td>2.28</td>
<td>3.06</td>
<td>3.91</td>
<td>4.74</td>
<td>5.51</td>
<td>5.70</td>
</tr>
<tr>
<td>GRAIN T.</td>
<td>50.1</td>
<td>49.8</td>
<td>49.5</td>
<td>49.0</td>
<td>47.9</td>
<td>44.4</td>
<td>43.6</td>
<td>43.8</td>
</tr>
<tr>
<td>MCCB %</td>
<td>13.34</td>
<td>13.75</td>
<td>14.33</td>
<td>14.92</td>
<td>16.73</td>
<td>17.33</td>
<td>20.09</td>
<td>21.78</td>
</tr>
<tr>
<td>REL HUM</td>
<td>0.470</td>
<td>0.483</td>
<td>0.502</td>
<td>0.528</td>
<td>0.618</td>
<td>0.816</td>
<td>0.859</td>
<td>0.915</td>
</tr>
<tr>
<td>ABS HUM</td>
<td>0.00360</td>
<td>0.00360</td>
<td>0.00370</td>
<td>0.00380</td>
<td>0.00400</td>
<td>0.00420</td>
<td>0.00450</td>
<td>0.00500</td>
</tr>
</tbody>
</table>

**FIGURE 41. An example output of distributions of the harvested corn to bins and the drying data of each bin**
** REPORT ON BIN DRYING AND STORAGE **

### (FINAL SHUTDOWN)

**BIN NO.**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEIGHT, FT</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>0.0</td>
</tr>
<tr>
<td>DIAMETER, FT</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>0.0</td>
</tr>
<tr>
<td>CAPACITY, BU</td>
<td>9935.8</td>
<td>9935.8</td>
<td>9935.8</td>
<td>9935.8</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**BIN**

<table>
<thead>
<tr>
<th>FAN</th>
<th>ON-OFF</th>
<th>KW</th>
<th>CFM/SF</th>
<th>CFM/BU</th>
<th>PRESSURE, IN</th>
<th>TEMP.RISE, F</th>
<th>MOISTURE, XWS</th>
<th>GRAIN TEMP., F</th>
<th>DET. RATE, %</th>
<th>EO. STO. HRS.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.3</td>
<td>2.5</td>
<td>3.79</td>
<td>2.8</td>
<td>15.9</td>
<td>14.1</td>
<td>0.022</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.4</td>
<td>2.5</td>
<td>3.77</td>
<td>2.8</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.2</td>
<td>2.5</td>
<td>3.80</td>
<td>2.9</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.0</td>
<td>2.5</td>
<td>4.17</td>
<td>3.0</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.2</td>
<td>2.5</td>
<td>4.17</td>
<td>3.0</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.0</td>
<td>2.5</td>
<td>4.17</td>
<td>3.0</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>OFF</td>
<td>13.2</td>
<td>22.2</td>
<td>2.5</td>
<td>4.17</td>
<td>3.0</td>
<td>15.2</td>
<td>14.0</td>
<td>0.012</td>
<td>14.0</td>
</tr>
</tbody>
</table>

**GRAIN**

<table>
<thead>
<tr>
<th>DATE IN</th>
<th>283</th>
<th>284</th>
<th>285</th>
<th>286</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>INIT. MOIS%</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>MAX. MC%</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TOTAL BU.</td>
<td>6813.1</td>
<td>6813.1</td>
<td>6813.1</td>
<td>6813.1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>ACT. DEPTH, FT</td>
<td>10.6</td>
<td>10.7</td>
<td>10.7</td>
<td>10.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>LAYERS</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>FRONT LAYER</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BU/LAYER, BU</td>
<td>496.8</td>
<td>496.8</td>
<td>496.8</td>
<td>496.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TOP LAYER, BU</td>
<td>280.6</td>
<td>280.6</td>
<td>280.6</td>
<td>280.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SHRINKAGE</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>FILLING</td>
<td>60 %</td>
<td>60 %</td>
<td>60 %</td>
<td>60 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>DATE STOP</td>
<td>321</td>
<td>321</td>
<td>321</td>
<td>321</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**OTHERS**

| MOISTURE, % | 14.1  | 14.1  | 14.1  | 14.1  | 0.0  | 0.0  |
| GRAIN TEMP., F | 37.0  | 37.0  | 37.0  | 37.0  | 0.0  | 0.0  |
| DET. RATE, % | 0.022 | 0.018 | 0.006 | 0.012 | 0.006 | 0.006 |

**BIN-FILLING MANAGEMENT METHOD:** CONTROLLED FILLING ACCORDING TO THE DRYING FRONT, 4 BINS USED.

FIGURE 42. An example output of summary report (final shutdown)
SUMMARY REPORTS ON THE 1960 PRODUCTION SEASON

- The total field assigned = 300.0 acres.
- The total field planted = 300.0 acres.
- The total field harvested = 300.0 acres.
- The total grain harvested = 29147.9 bushels.

<table>
<thead>
<tr>
<th>JULDAY</th>
<th>DATE EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MED.</td>
<td>116 205 272 296 35.000 107.200 0.0 0.0 6.400 100.800 19.532 0.0</td>
</tr>
<tr>
<td>2 MED.</td>
<td>117 206 272 294 35.000 107.200 0.0 0.0 6.000 101.200 20.194 0.0</td>
</tr>
<tr>
<td>3 MED.</td>
<td>121 206 272 292 40.000 107.200 0.0 0.0 5.600 101.600 20.656 0.0</td>
</tr>
<tr>
<td>4 MED.</td>
<td>122 206 272 290 40.000 107.200 0.0 0.0 5.200 102.000 21.109 0.0</td>
</tr>
<tr>
<td>5 SHRT</td>
<td>123 204 270 283 40.000 97.200 0.0 0.0 4.800 92.400 21.314 0.0</td>
</tr>
<tr>
<td>6 SHRT</td>
<td>124 205 271 288 40.000 97.200 0.0 0.0 4.400 92.800 21.663 0.0</td>
</tr>
<tr>
<td>7 SHRT</td>
<td>125 205 271 285 30.000 97.200 0.0 0.0 4.200 93.000 22.983 0.0</td>
</tr>
<tr>
<td>8 SHRT</td>
<td>126 205 271 285 30.000 97.200 0.0 0.0 4.200 93.000 22.983 0.0</td>
</tr>
</tbody>
</table>

Actual total harvesting period: 16 days.
Stalled due to wet moisture of corn for: 20 days.
Stalled due to no-go days before harvest for: 6 days.
Drying stops due to high humidity for: 1 day.
Drying stops due to low temperature for: 1 day.
Aeration stops due to high humidity for: 0 days.

Initial corn moisture (%MCDB) are:

| B1 | 30.7 | 30.7 | 30.7 | 30.7 | 29.2 | 28.1 | 28.1 | 27.5 | 26.0 | 25.7 | 25.7 | 25.7 | 25.7 | 25.7 |
| B2 | 30.0 | 30.0 | 30.0 | 30.0 | 29.5 | 28.6 | 27.3 | 27.3 | 26.6 | 26.6 | 26.6 | 26.6 | 26.6 | 26.6 |
| B3 | 29.8 | 29.8 | 29.8 | 29.8 | 28.0 | 27.1 | 26.8 | 26.8 | 26.6 | 26.6 | 26.6 | 26.6 | 26.6 | 26.6 |
| B4 | 29.3 | 28.7 | 28.7 | 28.7 | 27.7 | 26.3 | 26.0 | 26.0 | 26.0 | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 |

FIGURE 43. An example output of the management data (Cornsim results)
THE YEAR 1960

<table>
<thead>
<tr>
<th>DATE</th>
<th>OBSERVED (DAYS/WEEK)</th>
<th>PREDICTED (DAYS/WEEK)</th>
<th>DEVIATION (DAYS/WEEK)</th>
<th>RAIN</th>
<th>WD</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 9</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 16</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 19</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 23</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 37</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 41</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 55</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 72</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 79</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 86</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 95</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 100</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 107</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 114</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 121</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 128</td>
<td>6.0</td>
<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 135</td>
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<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>60 142</td>
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<td>0.0</td>
<td>-6.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

DATA=8.0 MEANS NO DATA AVAILABLE.

TOTAL WEEKS: 35
SUM OF OBSERVED DAYS (X): 187.4
SUM OF PREDICTED DAYS (Y): 190.0
SUM SQUARE OF X: 1090.0
SUM SQUARE OF Y: 1136.0
SUM OF PRODUCT X*Y: 1079.1

THE REGRESSION EQUATION: 
Y = (1.607097) + (0.713723) * X

FIGURE 44. An example output of results from the FLDAY model
APPENDIX C. JCL CONTROL CARDS FOR FLDA7 AND CORNDRY MODELS

Job Control Cards for the CORNDRY Model

//CsaacFON JOB Uxxxx,DINSUE
/*JOBPARM LINES=200
//STEP1 EXEC FORTHG,REGION.GO=256K,TIME.GO=5
//GO.SYSLIN DD DSN=F.U3383.FONOBJ,DISP=SHR
//GO.FT01F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(10,2),RLSE),
// DSN=F.U3383.BIN1,DCB=(RECFM=FB,LRECL=120,BLKSIZE=6120,BUFNO=1)
//GO.FT02F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(10,2),RLSE),
// DSN=F.U3383.BIN2,DCB=(RECFM=FB,LRECL=120,BLKSIZE=6120,BUFNO=1)
//GO.FT03F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(10,2),RLSE),
// DSN=F.U3383.BIN3,DCB=(RECFM=FB,LRECL=120,BLKSIZE=6120,BUFNO=1)
//GO.FT04F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(10,2),RLSE),
// DSN=F.U3383.BIN4,DCB=(RECFM=FB,LRECL=120,BLKSIZE=6120,BUFNO=1)
//GO.FT10F001 DD DSN=F.U3383.DATA60,DISP=SHR,DCB=BUFNO=1
//GO.FT11F001 DD DSN=F.U3383.DATA61,DISP=SHR,DCB=BUFNO=1
//GO.FT12F001 DD DSN=F.U3383.DATA62,DISP=SHR,DCB=BUFNO=1
//GO.FT13F001 DD DSN=F.U3383.DATA63,DISP=SHR,DCB=BUFNO=1
//GO.FT14F001 DD DSN=F.U3383.DATA64,DISP=SHR,DCB=BUFNO=1
//GO.FT15F001 DD DSN=F.U3383.DATA65,DISP=SHR,DCB=BUFNO=1
//GO.FT16F001 DD DSN=F.U3383.DATA66,DISP=SHR,DCB=BUFNO=1
//GO.FT17F001 DD DSN=F.U3383.DATA67,DISP=SHR,DCB=BUFNO=1
//GO.FT18F001 DD DSN=F.U3383.DATA68,DISP=SHR,DCB=BUFNO=1
//GO.FT19F001 DD DSN=F.U3383.DATA69,DISP=SHR,DCB=BUFNO=1
//GO.FT20F001 DD DSN=F.U3383.DATA70,DISP=SHR,DCB=BUFNO=1
//GO.FT21F001 DD DSN=F.U3383.DATA71,DISP=SHR,DCB=BUFNO=1
//GO.FT22F001 DD DSN=F.U3383.DATA72,DISP=SHR,DCB=BUFNO=1
//GO.FT23F001 DD DSN=F.U3383.DATA73,DISP=SHR,DCB=BUFNO=1
//GO.FT24F001 DD DSN=F.U3383.DATA74,DISP=SHR,DCB=BUFNO=1
//GO.FT25F001 DD DSN=F.U3383.DATA75,DISP=SHR,DCB=BUFNO=1
//GO.FT26F001 DD DSN=F.U3383.DATA76,DISP=SHR,DCB=BUFNO=1
//GO.FT27F001 DD DSN=F.U3383.DATA77,DISP=SHR,DCB=BUFNO=1
//GO.FT28F001 DD DSN=F.U3383.DATA78,DISP=SHR,DCB=BUFNO=1
//GO.FT29F001 DD DSN=F.U3383.DATA79,DISP=SHR,DCB=BUFNO=1
//GO.FT30F001 DD DSN=F.U3383.DATA80,DISP=SHR,DCB=BUFNO=1
//GO.SYSIN DD *
0 N-W IOWA
  15
150 2 150 3
116 134 148 155
92  7 121 8 135 9 170 8
305 263
24.
60  60
5.  2.5 300.
1072 1069 1117 1167 1141 852 1069 1019 957 1542
Job Control Cards for the FLDay Model

//CxxxFON JOB Uxx,x,DINSUE
//*JOBPARM LINES=20
//STEP1 EXEC FORTHG,REGION.GO=256K,TIME.GO=3
//GO.SYSLIN DD DSN=F.U3383.WDOBJG,DISP=SHR
//GO.FT01F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(10,2),RLSE),
//  DSN=F.U3383.BIN1,DCB=(RECFM=FB,LRECL=120,BLKSIZE=6160,BUFNO=1)
//GO.FT10F001 DD DSN=F.U3383.DATA60,DISP=SHR,DCB=BUFNO=1
//GO.FT11F001 DD DSN=F.U3383.DATA61,DISP=SHR,DCB=BUFNO=1
//GO.FT12F001 DD DSN=F.U3383.DATA62,DISP=SHR,DCB=BUFNO=1
//GO.FT13F001 DD DSN=F.U3383.DATA63,DISP=SHR,DCB=BUFNO=1
//GO.FT14F001 DD DSN=F.U3383.DATA64,DISP=SHR,DCB=BUFNO=1
//GO.FT15F001 DD DSN=F.U3383.DATA65,DISP=SHR,DCB=BUFNO=1
//GO.FT16F001 DD DSN=F.U3383.DATA66,DISP=SHR,DCB=BUFNO=1
//GO.FT17F001 DD DSN=F.U3383.DATA67,DISP=SHR,DCB=BUFNO=1
//GO.FT18F001 DD DSN=F.U3383.DATA68,DISP=SHR,DCB=BUFNO=1
//GO.FT19F001 DD DSN=F.U3383.DATA69,DISP=SHR,DCB=BUFNO=1
//GO.FT20F001 DD DSN=F.U3383.DATA70,DISP=SHR,DCB=BUFNO=1
//GO.FT21F001 DD DSN=F.U3383.DATA71,DISP=SHR,DCB=BUFNO=1
//GO.FT22F001 DD DSN=F.U3383.DATA72,DISP=SHR,DCB=BUFNO=1
//GO.FT23F001 DD DSN=F.U3383.DATA73,DISP=SHR,DCB=BUFNO=1
//GO.FT24F001 DD DSN=F.U3383.DATA74,DISP=SHR,DCB=BUFNO=1
//GO.FT25F001 DD DSN=F.U3383.DATA75,DISP=SHR,DCB=BUFNO=1
//GO.FT26F001 DD DSN=F.U3383.DATA76,DISP=SHR,DCB=BUFNO=1
//GO.FT27F001 DD DSN=F.U3383.DATA77,DISP=SHR,DCB=BUFNO=1
//GO.FT28F001 DD DSN=F.U3383.DATA78,DISP=SHR,DCB=BUFNO=1
//GO.FT29F001 DD DSN=F.U3383.DATA79,DISP=SHR,DCB=BUFNO=1
//GO.FT32F001 DD UNIT=DISK,DISP=(NEW,CATLG),SPACE=(TRK,(50,2),RLSE),
// DSN=F.U3383.DATA82,DCB=(RECFM=FB,LRECL=80,BLKSIZE=6160,BUFFNO=1)
//GO.SYSIN DD *
606022  21  125  125  9  2  30  40  0  0  0
/*
Program Lists for the CORNDRY Model

C THIS IS THE MAIN PROGRAM OF THE CORNDRY MODEL.
//C227FON JOB U3383,DINSUE
//STEP1 EXEC FORTGC,PARM.FORT='NOSOURCE'
//FORT.SYSLIN DD DSN=F.U3383.FONOBJ,UNIT=DISK,
// SPACE=(1920,(20,10)),DISP=(NEW,CATLG),
// DCB=(RECFM=FB,LECL=80,BLKSIZE=6160,BUFNO=1)
//FORT.SYSIN DD *

BLOCK DATA
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PLT1/IPLTST(5,2),PIPLT(5),IPLTDY(4),SIIFLD(30),
2 VTYGDU(3),YLDIPO(20),YLDPLT(3,3)
COMMON/FLDl/IHAR,IHARDY,HARMST,DDMST(5),9S3FLD(30),IND(30),DB
1 /FDL2/EQH.DDCOEI(5,3),WBDPRS
COMMON/HARV1/YLDCOM(2),YLDHAR(2),HARRAT(2),TIME,SN,
1 HARIAL, HARCHR,WRKID,RR
COMMON/IN/MSTO,JER(6),TDTR,TLOW,BCFM,RH0FF,TMOFF,JRHDY,KC,IC0DE
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPH(6),ALFA(6),WGD(6)
1 ,Delt,IFILL(6),IFAN(5),IFANON,IFILON,LAYER(6),NB,N,NN,NJL
COMMON/BZ/GHCM(6,20),GMD(6,20),GTEP(6,20),GSTM(6,20),SH(6,20),
1 GDTHS(6),GTHS(6,20),GCAV(6),NAI,
DATA DDCOEI/1.000,0.900,0.800,0.800,0.500,2.000,0.080,0.432,
*1.000,0.047,0.021,0.119,0.146,0.000/
DATA DDMST/75.,37.,25.,20./
DATA YLDPLT/0.5,0.0,0.0,1.0,1.0,1.0,75,2.0,1.5,1.5/
DATA YLDHAR/20,50/
DATA YLDCOM/2.0,4.0/
DATA IFLD/180*
DATA RFLD/210*
DATA SIIFLD/30*
DATA S3FLD/30*
DATA S4FLD/30*
DATA FRZMST/33/
DATA IDAY, KC/5*
DATA NB/1/
END
C

INTEGER IVAR(4), JPLTST(5,2), IHRPDY(6,2), PLACE(4), I2FLD(30),
1 ISLKDY(3), ITEMP(4)
COMMON /ALL/IPFLD, IFLD(30,6), IDAY(4), FRZMST, IWET, MAINC
COMMON/PLT1/IPLTST(5,2), PLTACR, RFLD(30,7), S4FLD(30)
1 /PLT2/PLTRAT, ACPLT(5), IPLTDY(4), S1FLD(30),
2 VTYGDU(3), YLDPLT(20), YLDPLT(3,3)
COMMON/FLD1/IHAR, IHRDY, HARMST, DDMST(5), S3FLD(30), IND(30), DB
1 /FLD2/EQM, DDC0EF(5,3), WBDPRS
COMMON/HARV1/YLDOM(2), YLDPOT(20), YLDPLT(3,3), HARRAT(2), TIME, SUM,
1 HARBUL, HARCRC, WRSHR, IDRY
COMMON/GN/GMCMB(6,20), DEPLAY(6,21), DEPTH(6), ALFA(6), WGD(6)
1 ,DELT, IFILL(6), IFAN(6), IFANON, IFILON, LAYER(6), NB, N, MB, JULDAY
COMMON/IN/HSTO, JER(6), TDTR, TLOW, BCFM, RHOFF, TMOFF, JRHDY, KC, ICODE
COMMON/CF/RES(6), FIL(6), HGBU, HGMC, INDAT(6), IC, XLOAD(6), ATBU(6)
COMMON/CN/CFMSF(6), FENG(6), BINF(6), BINBU(6), ACBU(6), TRANS, CAR, MODE
COMMON/BY/GMCOD(6,20), GMCDB(6,20), GTEMP(6,20), GSM(6,20), SM(6,20),
1 GDMAX(6), GDTR(6,20), GNC(6,20), MAXLAY
DATA IPRT, KFL, JJK, JUDO, TADD/4*0,0./
DATA FRZDMG/2.5/
DATA IVAR/ ' ', 'LONG', 'MED.', 'SHRT' /
DATA I2FLD/30*0/

C

800 READ(5,1200,END=900) MAINC, PLACE
1200 FORMAT(11,4A4)
READ(5,1000) MINFLD
READ(5,1000)((JPLTST(I,J),J=1,2),I=1,5)
READ(5,1000) IPLTDY
1000 FORMAT(15I4)
READ(5,1000)((IHRPDY(I,J),J=1,2),I=1,6)
READ(5,1000) IHRDY, IFDY
READ(5,1005) HARMST
READ(5,1000) IYRSTR, IYRSTP
READ(5,1005) PLTRAT, HARRAT
READ(5,1006) YLDPLT
READ(5,1005) VTYGDU
READ(5,1000) ISLKDY
1005 FORMAT(10F5.0)
1006 FORMAT(10F5.1/10F5.1)
READ(5,1000) IPRINT, IPUNCH
IF(MAINC.GE.2)GOTO 300
WRITE(6,1010 ) MAINC, PLACE
WRITE(6,1500) MAINC, PLACE
1500 FORMAT('1',1X,89('**')/2X,89('**')/2X,15('**')/59X,15('**')/2X,12('**')
2 7('**')/5X,7('**')/2X,5('**')/5X,'A.R.I.C.U.L.T.U.R.A.L E.N.G.'
5 10X,15('**')/2X,20('**')/49X,20('**')/2X,25('**')/9X,'UPDATE: JUNE 1'
DATA INPUT FOR A TYPICAL 4A4 FARM SIMULATION

YEAR RANGE : ST',

ENDING WITH THE 19',I2,' PRODUCTION SEASON'

RESTRICTIONS ON PLANTING DATE :

FIRST POSSIBLE DAY TO PLANT CORN :
LAST DAY TO PLANT LONG SEASON CORN :
LAST DAY TO PLANT MEDIUM SEASON CORN :
LAST DAY TO PLANT SHORT SEASON CORN :
MINIMUM GOOD SPRING FIELD DAYS :
PLANTING RATE (ACRES PER HOUR) :

WRITE(6,1011)(JPLTST(I,1),1=1,5),(IVAR(JPLTST(I,2)+1),1=1,5)
WRITE(6,202)((IHRPDY(I,J),I=1,6),J=1,2),IFDY,HARMST,IHARDY,HARRAT
WRITE(6,1520)YLDPOT,VTYGDU,ISLKDY
WRITE(6,1510)IPRINT,MAINC
WRITE(6,1530)
WRITE(6,1510)OUTPUT OPTIONS: PRINT=',I2,2X,' MAIN CONTROL=',I2

PLANTING STRATEGY : (MAXIMUM ',

FUNCTION DB,RH,0)

WRITE(6,1530)

OUTPUT OPTIONS: PRINT='I2,2X,' MAIN CONTROL='I2,40X,

PROGRAM DEVELOPED'

REMODELLED BY'

THE 19',I2,' PRODUCTION SEASON--FOR CORN'
1 21X,36('=',//)
IF(IYRSTP.GE.IYRSTR.AND.IHRPDY(1,1).GT.0)GOTO 98
WRITE(6,1111)
1111 FORMAT('ERROR MESSAGE: WRONG YEAR RANGE, OR ZERO IHRPDY VALUES. *')
GOTO 800
98 NTape=IYRSTR-50
NYR=IYRSTR
IYR=IYRSTR-59
100 DO 10 I=1,2
DO 10 J=1,5
10 IPLTST(J,1)=JPLTST(J,1)
DO 20 J=1,30
S3FLD(J)=0.
20 IFLD(J,4)=0.
DO 50 I=1,5
50 ACPLT(I)=FLOAT(IPLTST(1,1))
IFRZCT=0
IWRKDY=0
IPP=0
IDOE=0
JULOLD=0
IHAR=0
IH=1
JGO=0
KGO=0
JHAR=0
KIHAR=0
KHTB=0
KRHA=0
IPFLD=0
IDRY=0
PLTACR=0
HARACR=0
HARBUL=0
ISILK=1
IPLANT=1
IST=1
K=0
Jc=1
ICC=1
MC=1
K7=0
WRKHRS=IHRPDY(IH,2)
DEL0=24.
IF(MAINC.LE.1)GOTO 510
NREAD=30
IF(MAINC.GE.3)NREAD=5
IPRT=1
KC=0
510 CONTINUE
   IF(MAINC.LE.1)GOTO 509
   IF(KFL.EQ.0)GOTO 600
   KFL=KFL-1
   JULDAY=JULDAY+1
   GOTO 410
600 READ(NREAD,3100,END=701)KCAR.D,KFL,IDAY,DELO,DB,RH,NB,HGMC,GIN
   JULDAY=IDAY(4)
   IF(DELO.EQ.0)GOTO 423
605 IF(GIN.EQ.0.)GOTO 410
   ATBU(NB)=ATBU(NB)+GIN
   ACBU(NB)=ACBU(NB)+GIN
   IF(INDAT(NB).EQ.0)INDAT(NB)=JULDAY
   IF(IFAN(NB).GE.1)GOTO 610
   IFAN(NB)=2
   IFANON=IFANON+1
610 IF(IFILL(NB).EQ.0.)IFILON=IFILON+1
   IFILL(NB)=ATBU(NB)/BINBU(NB)*100.
   N=LAYER(NB)
   CALL BINFIL(GIN,DB)
   CALL FAN(NB)
   KCARD=KCARD-1
   IF(KCARD.EQ.0)GOTO 410
   READ(NREAD,3110)NB,HGMC,GIN
   GOTO 605
509 READ(NTAPE,1015,END=700)IDAY,ITEMP,WB,WBDPRS,RH,IFREZ,EQM,GDU,
   1 CUMGDU,ISNOW,RAIN,IGO,PAN
1015 FORMAT(3I2,5I3,3F3.0,I1,1X,F5.4,F3.0,F5.0,I4,F4.2,1X,I1,2X,F4.2)
   IFREZ=0
   IF(ITEMP(2).LE.28)IFREZ=1
   DB=ITEMP(3)
   JULDAY=IDAY(4)
   IF(JULDAY-JULOLD.GT.1)DELT=DELT*FLOAT(JULDAY-JULOLD)
410 DELT=DELO
   KPRINT=IPRINT
   IF(IPRT.EQ.0)GOTO 423
   IF(IFILON.EQ.0)GOTO 423
   IF(IPRINT.LE.3)GOTO 423
   IF(JULDAY-91)511,470,418
418 IF(JULDAY-140)440,450,419
419 IF(JULDAY-350)440,430,511
423 JULOLD=JULDAY
   IF(MAINC.GE.2)GOTO 510
   IWRKDY=IWRKDY+IGO
   IF(IHRPDY(IH+1,1).EQ.0)GOTO 55
   IF(JULDAY.LT.IHRPDY(IH+1,1))GOTO 55
   IH=IH+1
WRKHSR=IHRPDY(IH,2)
55 CONTINUE
   IF(IWRKD.Y.LE.MINFLD) GO TO 510
   IF(JULD.Y.LT.IPLTDY(1))GOTO 510
   IF(IPLANT.EQ.0) GO TO 525
   IF(JULD.GT.IPLTDY(4))GO TO 525
   DO 56 I=IST,5
   IF(ACPLT(I).NE.0.)GOTO 521
56 CONTINUE
   IPLANT=0
   GO TO 525
521 IST=I
520 IF(IGO.NE.0)CALL PLANT(JULD,Y,WRKHSR,IST,IYR,CUMGU)
   IF(IPFLE.LE.30) GOTO 525
   IPFLE=30
   IPLANT=0
525 CONTINUE
   IF(JULD.LT.150) GO TO 510
   IF(IDOE.EQ.IPFDY) GO TO 540
   DO 57 J=ISILK,IPFDY
      IF(IFLD(J,1).EQ.1.AND.CUMGU.GE.SIFLD(J))GOTO 526
      GOTO 527
526 IFLD(J,1)=2
   I2FD(J)=JULDY
   I2FD(J,6)=ISILKDY(IFLD(J,6))
   IDOE=IDOE+1
   IF(J.GT.ICC)ICC=J
527 IF(IFLD(JC,1).GT.1)JC=JC+1
57 CONTINUE
   ISILK=JC
540 CONTINUE
   IF(IDOE.EQ.0) GO TO 555
   DO 550 K=MC,ICC
      IF(I2FD(K).NE.JULDY) GOTO 550
      IFLD(K,1)=3
      S3FD(K)=DDMST(1)
      IDRY=IDRY+1
550 CONTINUE
555 IF(IDRY.EQ.0) GO TO 560
   IF(IPFLE.EQ.0.AND.IPRINT.GE.2)GOTO 557
   GOTO 558
557 WRITE(6,1012)IYR
   WRITE(6,1011)(IPLTST(I,1),I=1,5),IPLTST(I,2)+1,I=1,5)
   WRITE(6,1013)(I,1=1,IPFDY)
   IPP=1
1013 FORMAT(//27X,43(***)/27X,** CHANGES OF CORN MOISTURE IN THE FIELD
1 ***/27X,***,39X,/***/27X,***,11X,MAXIMUM: 30 FIELDS',8X,***'
2/27X,43(***)/' DATE/JULIAN',32X,'FIELD NUMBER'/1X,10(',='),30X,18
3 '='/12X,30Y/30(' ==='))
558 CALL FLDDRY(JULDY,IPRINT)
560 CONTINUE
   IF(IFRZCT.EQ.1.OR.JULDAY.LE.220) GO TO 563
   IF(IFREZ.EQ.1.AND.IPRINT.GE.2)CALL FREEZE(IFRZCT,FRZDMG)
563 IF(JULDAY.LT.IDY) GOTO 510
   IF(IHR.EQ.0.AND.KHR.GT.2) GOTO 510
   IF(IHR) 565,565,566
565 JHR=JHR+1
   IF(IGO.EQ.0) KGO=KGO+1
   GOTO 510
566 KHR=KHR+1
   IF(IGO.EQ.1) GOTO 570
   JGO=JGO+1
   GOTO 510
570 IF(JJK.EQ.1) GOTO 429
   IPRT=1
   JJK=1
   KC=0
   CALL INFO(DB,RH,1)
429 CALL CONTROL(IGO)
   GOTO 510
425 DO 25 NBB=1,MB
   IF(IFAN(NBB).EQ.0) GOTO 25
   N=LAYER(NBB)
   IF(IFAN(NBB).LT.2) GOTO 24
   IF(RH.LE.RH0FF) GOTO 426
   IF(JULDAY.LT.JRHDY) GOTO 426
   IF(JULDAY.LT.140) GOTO 426
   IF(JUDO.EQ.JULDAY) GOTO 24
   WRITE(6,2060) IDAY,RH,RHOFF
   KRH=KRH+1
   JUDO=JULDAY
   GOTO 24
426 IF (DB.GE.TLOW) GOTO 326
   IF(JUDO.EQ.JULDAY) GOTO 24
   WRITE(6,2070) IDAY,DB,TLOW
   KTB=KTB+1
   JUDO=JULDAY
   GOTO 24
326 CALL DRYING(DB,RH,NBB)
   CALL DRYMOD(NBB)
24 CALL STORE(NBB,DB)
25 CONTINUE
   IF(JULDAY.NE.JULOLD.AND.IFANON.GT.0) CALL PRINT2(DB,RH,KPRINT)
   IF(IPRINT.LT.7.OR.IPRINT.GT.8) GOTO 423
   K7=K7+1
   IF(K7.LT.7) GOTO 423
   K7=1
   KL=2
427 CALL INFO(DB,RH,KL)
   GOTO 423
430 KL=3
    IHAR=0
    IDRY=0
    GOTO 435
440 IF(IFANON.GT.0)GOTO 425
    KL=5
    GOTO 435
450 KL=4
    IFILON=0
    IF(IPRT.EQ.1)KL=5
    KC=0
    GOTO 48
470 KC=0
    IF(IFANON.EQ.0)GOTO 435
    DELT=DELO
    WRITE(6,2050)
2050 FORMAT( '1'/10X,'**** CONTINUE DRYING FROM LAST YEAR ****'/)
    K7=6
    DO 44 I=1,MB
    IF(IFAN(I).EQ.1)IFAN(I)=2
44 CONTINUE
    GOTO 440
511 IF(JULDAY.EQ.366)TADD=24.
    IF(MSTO.GT.0)GOTO 434
    IF(JULDAY.NE.90)GOTO 423
    DELT=2544.+TADD
    KL=6
    TADD=0.
    GOTO 436
435 IF(MSTO.EQ.0)GOTO 46
434 DELT=THOFF
    KL=6
436 DO 45 NBB=1,MB
    IF(IFILL(NBB).EQ.0)GOTO 45
    IF(IFAN(NBB).EQ.0)GOTO 45
    N=LAYER(NBB)
    IF(MSTO.LE.1)GOTO 42
41 IF(RH.LE.RHOFF)GOTO 770
    IF(NBB.GT.1)GOTO 42
    WRITE(6,2060)IDAY,RH,RHOFF
    KRHA=KRHA+1
    GOTO 42
770 IF(JER(NBB).EQ.0)GOTO 42
    CALL DRYING(DB,RH,NBB)
    CALL DRMOD(NBB)
    CALL STORE(NBB,DB)
    GOTO 45
42 CALL STORE(NBB,DB)
45 CONTINUE
    IF(MSTO.GT.1)CALL PRINT2(DB,RH,KPRINT)
190

46 IF(KL.EQ.6)GOTO 423
  IF(IPRT.EQ.0)GOTO 423
  IF(KL.EQ.3)GOTO 427
48 IPRT=0
  JJK=0
  GOTO 427
700 CALL PRINT1(NYR,HARCR,HARBUL)
  IF(MAINC.EQ.1)GOTO 730
  WRITE(6,2080)KXR,HAR,KGO,JGO,KRH,KTB,KRC
701 DO 65 I=1,MB
  NNN=NNN+1
  GOTO 427
65 WRITE(6,2090)I,(GMCOD(I,J),J=1,NNN)
2080 FORMAT(1X,'*** ACTUAL TOTAL HARVESTING PERIOD ARE: ','I4,'DAYS.'/6X,
  'STALLED DUE TO WET MOISTURE OF CORN FOR:','I4,'DAYS.'/6X,
  'STALLED DUE TO NO-GO DAYS BEFORE HARVEST FOR:','I4,'DAYS.'/6X,
  'STALLED DUE TO NO-GO DAYS DURING HARVEST FOR:','I4,'DAYS.'/6X,
  'DRIYING STOPS DUE TO HIGH HUMIDITY FOR:','I4,'DAYS.'/6X,'AERATION' *
  'STOPS DUE TO LOW TEMPERATURE FOR:','I4,'DAYS.'/6X,'DRYING' 5
  'STOPS DUE TO HIGH HUMIDITY FOR:','I4,'DAYS.'/6X
  'THE INITIAL CORN MOISTURE(MCDB%) ARE :'/)
2090 FORMAT(1X,'B',11.4(2X,5(F4.1,1X)))
  IF(MAINC.GE.2)GOTO 900
730 NYR=NYR+1
  IYR=IYR+1
  NTAPE=NTAPE+1
  IF(NYR.GT.IYRSTP)GOTO 800
  GOTO 100
2060 FORMAT(1X,'----AERATION STOPS ON ','I2,.'/'),13,'THE ',
  'RELATIVE HUMIDITY IS ','F4.1,'% HIGHER THAN THE PRESET VALUE'
  'AIR TEMPERATURE IS ','F4.1,' F LOWER THAN THE PRESET VALUE'
2070 FORMAT(1X,'-----DRYING STOPS ON ','I2,.'/'),13,'THE ',
  'AIR TEMPERATURE IS ','F4.1,' F LOWER THAN THE PRESET VALUE'
900 STOP
END
C
SUBROUTINE FLDDRY(JULDAY,IPRINT)
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PLT1/IPLTST(5,2),PLTACR,RFLD(30,7),S4FLD(30)
COMMON/FLD1/IHXR, IHARDY, HARMST,DDMST(5),S3FLD(30),IND(30),DB
1 /FLD2/EFM,DDCOEF(5,3),WBDPRS
EVM=EFM*100./(1+EFM)
  IF(EVM.GT.30.)EVM=30.
  HRMST=HARMST
  IF(JULDAY.GT.IHARDY)HRMST=DDMST(3)
DO 665 L=1,IPFLD
  K= IFLD(L,1)
  KD=K-2
  IF(KD.GT.5)KD=5
  IF(K.LT.3 .OR. K.EQ.9) GO TO 665
IF(S3FLD(L).LT.FRZMST.AND.IFLD(L,4).EQ.0)IFLD(L,4)=JULDAY
IF(K.LT.7)G0 TO 300
S3FLD(L)=S3FLD(L)-DDCOEF(KD,1)*(S3FLD(L)-(EQM+DDCOEF(KD,2)))
GOTO 100
300 IF(K.GT.4)G0 TO 200
S3FLD(L)=S3FLD(L)-DDCOEF(KD,1)*(-DDCOEF(KD,2)+DDCOEF(KD,3)*DB)
IF(S3FLD(L).LT.DDMST(3))GOTO 303
IF(S3FLD(L).LT.DDMST(2))GOTO 304
GOTO 665
303 IFLD(L,1)=5
GOTO 100
304 IFLD(L,1)=4
GOTO 665
200 RDMST=DDCOEF(KD,1)*(-DDCOEF(KD,2)+DDCOEF(KD,3)*WBPRS)
IF(RDMST.LE.0.0)RDMST=0.0
RDMST1=DDCOEF(5,1)*(S3FLD(L)-(EQM+DDCOEF(5,2)))
IF(RDMST.EQ.0.AND.RDMST1.LT.0.)RDMST=RDMST1
S3FLD(L)=S3FLD(L)-RDMST
IF(S3FLD(L).LT.DDMST(4))IFLD(L,1)=6
IF(S3FLD(L).LT.DDMST(5))IFLD(L,1)=7
100 IF(K.EQ.8)GOTO 665
IHaR=IHar+1
IFLD(L,1)=8
IND(IHaR)=L
IF(IHaR1.EQ.1)GOTO 155
DO 150 I=1,IHaR
J=IHaR-I+1
IF(S3FLD(L).GT.S3FLD(IND(J)))GOTO 151
150 CONTINUE
GO TO 152
151 IF(J.EQ.IHaR)GOTO 155
J=J+1
152 DO 153 I=J,IHaR
JJ=IHaR+J-I
IND(JJ+1)=IND(JJ)
IND(JJ)=L
155 IHaR=IHar1
665 CONTINUE
IF(IPRINT.GE.2)WRITE(6,1050)IDAY,(S3FLD(I),1=1,IPFLD)
1050 FORMAT(1X,2(I2,'-'),I2,'/M3,30F4.0)
RETURN
END
C

SUBROUTINE H&RV(JULDAY,HGBU,HGMC,K)
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PLT1/IPLTST(5,2),PLTACR,RFLD(30,7),S4FLD(30)
COMMON/FLD1/IHAR,IHARDY,HARMST,DDMST(5),S3FLD(30),IND(30),DB
COMMON/HARV1/YLDCOM(2),YLDHAR(2),HARRAT(2),TIME,SUM,
1   HARBUL, HARACR, WRKRS, IDRY
DATA IOLD/0/
IF(K.EQ.0)TIME=WRKRS
10 IF(IHAR.GT.0)GOTO 89
    HGBU=0.
    RETURN
89 I=IND(1)
    IF(I.EQ.IOLD)GOTO 405
    IF(JULDAY.LT.320)GOTO 401
       RFLD(I,5)=YLDCOM(2)+YLDHAR(1)*45.+YLDHAR(2)*JULDAY-319
       GOTO 400
401 IF(JULDAY.LT.275)GOTO 402
       RFLD(I,5)=YLDCOM(1)+YLDHAR(1)*JULDAY-274
       GOTO 400
402 RFLD(I,5)=YLDCOM(1)
400 RFLD(I,6)=RFLD(I,2)-RFLD(I,3)-RFLD(I,4)-RFLD(I,5)
    RFLD(I,7)=S3FLD(I)
    IFLD(I,5)=JULDAY
    HVRATE=HARRAT(2)/RFLD(I,6)
    IF(HVRATE.GT.HARRAT(1))HVRATE=HARRAT(1)
    HGMC=S3FLD(I)
405 A1=HVRATE*TIME
    A2=S4FLD(I)
    A3=SUM/RFLD(I,6)
    IF(A1-A2)406,407,407
406 IF(A1-A3)410,410,430
407 IF(A2-A3)420,420,430
410 A0=A1
    GOTO 450
420 IHAR=IHAR-1
    IDRY=IDRY-1
    IFLD(I,1)=9
    S3FLD(I)=0.
    A0=A2
    IF(IHAR.EQ.0)GOTO 201
    DO 200 J=1,IHAR
200 IND(J)=IND(J+1)
    GOTO 450
201 IND(1)=0
    GOTO 450
430 A0=A3
450 TIME=TIME-A0/HVRATE
    HGBU=A0*RFLD(I,6)
    S4FLD(I)=S4FLD(I)-A0
    HARBUL=HARBUL+HGBU
    HARACR=HARACR+A0
    IOLD=I
    RETURN
END
SUBROUTINE CONTRL(IGO)
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PI/PLTST(5,2),PLTACR,RFLD(30,7),SAFLD(30)
COMMON/FLD/FIAR,IIARDY,HIAMST,DDMST(5),S3FLD(30),IND(30),DB
COMMON/HARV/YLDCOM(2),YLDHAR(2),HARRAT(2),TIME,SUM,
1   HARBUL, HARACR,WRKHERS,IDRY
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1   ,DEL,T,IFFl(6),IFAN(6),IFAN0,LAYE(6),NB,N,MB,JULDAY
COMMON/CN/CFMSF(6),FINC(6),BINC(6),BEBU(6),ACBU(6),TRANS,CAR,MODE
COMMON/CF/RES(6),FILL(6),HGBU,HCWTC,INDAT(6),IC,XLOAD(6),ATBU(6)
COMMON/DY/GMCMA(6),CUMKWH(6),FANHRS(5),MAV,MPEX,TVDF(6),JODAT(6)
DATA IODD/0/
IF(IHAAR.EQ.0.OR.IGO.EQ.0)RETURN
INDI=IND(1)
HGMC=S3FLD(IND1)
IF(HGMC.EQ.0.)RETURN
IF(MAINC.EQ.1)GOTO 160
THICK=4.
IF(HGMC.GT.24.)THICK=2.
IF(IC.EQ.1)AIR=FLOW(HGMC)
SUM=0.
IF(JULDAY.EQ.140)IODD=0
IF(IC.LE.5)GOTO 400
IF(IODD.EQ.0)GOTO 398
IODD=IODD+1
IF(IODD+5.GE.IC)IODD=0
DO 6 I=1,MB
5 SUM=SUM+FILL(NB)
GOTO 200
398 IODD=IODD+1
400 DO 150 I=1,MB
RR=ALFA(I)
IF(IFILL(I).GT.99)GOTO 40
IF(IFILL(I).EQ.0)GOTO 30
IF(I.EQ.NB)GOTO 100
5 IF(IC.GT.2)GOTO 50
IF(IC.LE.1)GOTO 10
FILL(I)=THICK
IF(XLOAD(I).GT.1.)FILL(I)=XLOAD(I)
GOTO 15
10 FILL(I)=CFMSF(I)*1.245/AIR-WGD(I)
15 LAYCR=LAYE(I)/2+1
IF(LAYCR.LT.1)LAYCR=1
IF(HGMC.GT.24.)AND.FILL(I).GT.2.)FILL(I)=2.
IF(FILL(I).GT.4.)FILL(I)=4.
IF(HGMC.GT.22.)AND.LAYDF(I).LT.LAYCR)FILL(I)=0.
IF(FILL(I).EQ.0.)GOTO 150
20 FILMIN=2.
FILMAX = BINH(I) - DEPTH(I)
IF (FILMAX .LT. FILMIN) FILMIN = FILMAX
IF (FILL(I) .GT. FILMAX) FILL(I) = FILMAX
IF (FILL(I) .LT. FILMIN) FILL(I) = 0.
FILL(I) = FILL(I) * RR
GOTO 100
30 IF (IC .EQ. 5) GOTO 65
FILL(I) = THICK * RR
GOTO 100
40 FILL(I) = 0.
GOTO 100
50 IF (IC .GT. 3) GOTO 55
IF (LAYDF(I) .LT. LAYER(I)) GOTO 40
FILL(I) = THICK
53 IF (XLOAD(I) .GT. 1.) FILL(I) = XLOAD(I)
GOTO 20
55 IF (IC .GT. 4) GOTO 60
56 FILL(I) = 2.
GOTO 53
60 IF (IC .EQ. 5) GOTO 65
GOTO 53
65 FILL(I) = BINBU(I) - ATBU(I)
100 IF (FILL(I) .EQ. 0.) GOTO 150
STM = STM + FILL(I)
150 CONTINUE
IF (SUM .LT. CAR) RETURN
GOTO 200
160 SUM = 100000
200 CALL HARV(JULDAY,HGBU,HGMC,0)
130 SUM = SUM - HGBU
HGBU1 = HGBU
IF (MAINC .NE. 1) GOTO 135
WRITE(6,503) IND1, DB, HGMC, HGBU
503 FORMAT('**FIELD NO.', I2, ' TEMP.=', F4.1, ' F. MC%=', F5.1, ' BU.=',
1 F6.1)
GOTO 600
135 CALL DISFIL(DB)
WRITE(6,500) HGBU1, IND1, (I, RES(I), I = 1, MB)
DO 140 I = 1, MB
140 RES(I) = RES(I) / TRANS * 60.
WRITE(6,501) HGMC, (RES(I), I = 1, MB)
WRITE(6,502) DB, (ATBU(I), I = 1, MB)
500 FORMAT('***', 'HARVEST', F6.0, ' BU. FROM NO.', I2, ' FIELD TO BIN ',
1 'NO.:', 6(1X, I1, 'F6.0, ', F6.0, ' BU.'))
501 FORMAT('***', 'MOISTURE:', F5.1, '%', 15X, 'LOADING TIME:', 6(3X,
1 F6.0, ' MIN'))
502 FORMAT('***', 'GRAIN TEMP:', F5.1, ' F', 9X, 'TOTAL BU. IN BIN:',
2 6(F9.0, ' BU. '))
600 IF (IHIAR .EQ. 0) RETURN
TIME = TIME -.5
IF(SUM.LE.5..OR.TIME.LT.0.)RETURN
IF(IND(1).NE.IND1)IND1=IND(1)
CALL HARV(JULDAY,HGBU,HGMC,1)
GOTO 130
END

FUNCTION FLOW(HGMC)
IF(HGMC.LT.23.)GOTO 11
FLOW=HGMC-20.
GOTO 12
11 FLOW=(HGMC-17.)*.5
12 IF(FLOW.LT..5)FLOW=.5
RETURN
END

SUBROUTINE DISFIL(HGT)
COMMON/GN/GHCW(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1,DELT,IFILL(6),IFAN(6),IFANON,IFILON,AYER(6),NB,N,MB,JULDAY
COMMON/CN/CHMF(6),FINC(6),BINH(6),BNBU(6),ACBU(6),TRANS,AR,MODE
COMMON/CF/RES(6),FILL(6),HGBU,HGMC,INDAT(6),IC,XLOAD(6),ATBU(6)
IF(HGBU.EQ.0.)RETURN
IFIL2=0
DO 1 I=1,MB
1 RES(I)=0.
3 IF(MB.EQ.1)GOTO 80
IF(IFILL(NB).GT.99)GOTO 60
IF(FILL(NB).GT.0.)GOTO 80
60 IF(IC.GT.3)GOTO 65
NN=NB
DO 55 I=1,MB
IF(I.EQ.NN)GOTO 55
IF(FILL(I)-FILL(NN))55,50,53
50 IF(ATBU(I)-ATBU(NN))53,51,55
49 IF(GHCW(I,AYER(I))=GHCW(NN,AYER(NN)))53,51,55
51 IF(I-NN)53,55,55
53 NN=I
55 CONTINUE
IF(NN.EQ.NB)GOTO 45
NB=NN
GOTO 80
65 NB=NB+1
IF(NB.GT.MB)NB=1
IFIL2=IFIL2+1
IF(IFIL2.GT.6)GOTO 45
80 HGBU0=HGBU-FILL(NB)
IF(HGBU0)5,10,17
5 FILL(NB) = FILL(NB) - HGBU
8 GIN = HGBU
   HGBU = 0.
   GOTO 20
10 GIN = HGBU
   HGBU = 0.
   GOTO 16
17 GIN = FILL(NB)
   HGBU = HGBU
16 FILL(NB) = 0.
20 ATBU(NB) = ATBU(NB) + GIN
   ACBU(NB) = ACBU(NB) + GIN
   RES(NB) = GIN
   IF(INDAT(NB).EQ.0) INDAT(NB) = JULDAY
   IF(IFAN(NB).GT.0) GOTO 25
   IFAN(NB) = 2
   IFANON = IFANON + 1
25 IF(IFILL(NB).EQ.0) IFILON = IFILON + 1
30 IFILL(NB) = ATBO(NB) / BINBU(NB) * 100.
35 IF(HGBU.EQ.0.) RETURN
   GOTO 3
45 WRITE(6,100) HGBU, IFIL2, NB
   RETURN
   END

SUBROUTINE FAN(NB)
   COMMON/GN/GMCWB(6,20), DEPLY(6,21), DEPTH(6), ALFA(6), WGD(6)
   DELT, IFILL(6), IFAN(6), IFANON, IFILON, LAYER(6), NO, N, MB, JULDAY
   COMMON/FN/FMCH(6,2,10), AREA(6), FANSP(6), CBU(6), FANKW(6)
   SUPHT(6), GTA(6), DTR(6,20)
   COMMON/CN/CFMSF(6), FINC(6), BINH(6), BINBU(6), ACBU(6), TRANS, CAR, MODE
   DATA EPS/.0001/
   EXTERNAL VALUE
   IF(CFMSF(NB).EQ.0.) CFMSF(NB) = BINBU(NB) / AREA(NB)
   CALL ROOT(CFMSF(NB), FANSP(NB), VALUE, EPS)
   CBU(NB) = CFMSF(NB) * AREA(NB) / ACBU(NB)
   RETURN
   END

SUBROUTINE ROOT(Q0, T0, FUNCQ, EPS)
   Q1 = Q0
   Q2 = FUNCQ(Q1, T0)
   Q3 = (Q1 + Q2) * 0.5
DO 10 I=1,20
Q4=FUNCQ(Q3,TP0)
P0=Q4-Q3
IF(ABS(P0).LE.EPS)GOTO 20
P1=Q2-Q1-P0
IF(P1.NE.0.)GOTO 40
30 Q5=(Q4+Q3)*.5
GOTO 50
40 Q5=Q3+P0*(Q3-Q1)/P1
50 Q1=Q3
Q2=Q4
Q3=Q5
10 CONTINUE
WRITE(6,100)
100 FORMAT(' DO-LOOP HAS BEEN DONE 20 TIMES')
20 Q0=Q4
RETURN
END

FUNCTION VALUE(Q,Z)
COMMON/GN/A(246),DEPTH(6),B(13),JJ(20),NB,N,MB,JULDAY
COMMON/IN/MSTO, JER(6),TDTR,TLOW,BCFM,RHOFF,TMOFF,JRHDY,KC,ICODE
COMMON/FN/X(6,2,10),AREA(6),FANSP(6),CBU(6),FANKW(6),D(132)
DATA A1,A2,A3,A4,A5,A6/14.5566,.1342,.00065,.156,2412.87,321.72/
IF(BCFM.EQ.0)GOTO 5
PACK=1.+(A1-A2*Q)*BCFM
GOTO 10
5 PACK=1.5
10 Z=DEPTH(NB)*A3*Q*Q/ALOG(1.+A4*Q)*PACK
IF(X(NB,1,1).LT.0.)GOTO 50
30 DO 35 J=2,10
IF(Z-X(NB,1,J)>36,40,35
35 CONTINUE
J=10
GOTO 40
36 J=J-1
37 VALUE=(X(NB,2,J)+(X(NB,2,J+1)-X(NB,2,J))/(X(NB,1,J+1)-X(NB,1,J)))*
1 (Z-X(NB,1,J))/AREA(NB)
RETURN
40 VALUE=X(NB,2,J)/AREA(NB)
RETURN
50 VALUE=FANKW(NB)*(A5-A6*Z)/AREA(NB)
RETURN
END

SUBROUTINE BINFIL(GIN,HGT)
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1 ,DELT,IFILL(6),IFAN(6),IFANON,IFILON,LAYER(6),NB,N,MB,JULDAY
COMMON/CF/RES(6),FILL(6),HGBU,HGMC,INDAT(6),IC,XLOAD(6),ATBU(6)
COMMON/BY/GMCOD(6,20),GMCDB(6,20),GTEMP(6,20),GSTM(6,20),SM(6,20),
1 GDTMAX(6),GDTR(6,20),GMCAV(6),MAXLAY
DDM(W)=100.*W/(100.-W)
ULAY=DEPLAY(NB,21)
GALL=DEPLAY(NB,N)+GIN/ALFA(NB)
IF(GALL-ULAY)5,5,6
5 R1=DEPLAY(NB,N)/GALL
K=0
GOTO 15
6 IF(N.EQ.MAXLAY)GOTO 5
K=1
R1=DEPLAY(NB,N)/ULAY
15 GMCWB(NB,N)=GMCWB(NB,N)*R1+HGMC*(1.-R1)
SM(NB,N)=GMCWB(NB,N)
GTEMP(NB,N)=GTEMP(NB,N)*R1+HGT*(1.-R1)
GMCDB(NB,N)=DDM(GMCWB(NB,N))
GMCOD(NB,N)=GMCOD(NB,N)*R1+DDM(HGMC)*(1.-R1)
IF(K.EQ.O)GOTO 35
20 IF(N.EQ.MAXLAY)GOTO 35
DEPLAY(NB,N)=ULAY
DEPTH(NB)=DEPTH(NB)+ULAY
N=N+1
GALL=GALL-ULAY
GMCWB(NB,N)=HGMC
SM(NB,N)=HGMC
GTEMP(NB,N)=HGT
GMCOD(NB,N)=DDM(HGMC)
GMCDB(NB,N)=GMCOD(NB,N)
IF(GALL-ULAY)35,35,20
35 DEPLAY(NB,N)=GALL
DEPTH(NB)=DEPTH(NB)+GALL
40 LAYER(NB)=N
RETURN
END

C
SUBROUTINE DRYHOD(NB)
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1 ,DELT,IFILL(6),IFAN(6),IFANON,IFILON,LAYER(6),NO,N,NB,JULDAY
COMMON/BY/GMCOD(6,20),GMCDB(6,20),GTEMP(6,20),GSTM(6,20),SM(6,20),
1 GDTMAX(6),GDTR(6,20),GMCAV(6),MAXLAY
COMMON/FN/FANCAH(6,2,10),AREA(6),FANSF(6),CBU(6),FANFKW(6)
1 ,SUPHT(6),GTAV(6),DTR(6,20)
COMMON/DY/GMCMA(6),CMKWH(6),FANHRS(6),GMAV,GMAX,LAYDF(6),JODAT(6)
COMMON/CM/CFMSF(6),FINC(6),BINH(6),BINBU(6),ACBU(6),TRANS,CAR,MODE
COMMON/IN/HTO,JER(6),TDTR,TLOW,BCFM,RHCOFF,TMOFF,JRHDDY,KT,ICODE
DATA IPASS,C1,C2/0,.0176,.85/
IF(IFAN(NB).EQ.O)RETURN
IF(N.EQ.1) GOTO 26
N1=LAYDF(NB)
DO 10 I=N1,N
IF(GMCWB(NB,I).LE.17.5)GOTO 10
IF(GMCWB(NB,I).LT.GMCWB(NB,I-1)+.3)GOTO 25
GOTO 20
10 CONTINUE
LAYDF(NB)=N
GOTO 26
20 IF(I.GT.1)LAYDF(NB)=I-1
GOTO 26
25 LAYDF(NB)=I
26 WGD(NB)=DEPTH(NB)-FLOAT(LAYDF(NB))*DEPLAY(NB,21)
FMHRS(NB)=FANHRS(NB)+DELT
CUMKWH(NB)=CUMKWH(NB)+DELT*FANKW(NB)/C2
IF(SUPHT(NB).GT.100.)CUMKWH(NB)=CUMKWH(NB)+DELT*SUPHT(NB)*C1
GMCAV(NB)=0.
GMCMa(NB)=0.
GTAV(NB)=0.
DO 30 I=1,N
J=N-I+1
IF(GHCWB(NB,J).GT.GMCMA(NB))GMCMA(NB)=GMCWB(NB,J)
IF(I.EQ.N)GOTO 31
GMCAV(NB)=GMCAV(NB)+GMCWB(NB,I)
GTAV(NB)=GTAV(NB)+GTEMP(NB,I)
30 CONTINUE
31 RR=DEPLAY(NB,N)/DEPLAY(NB,21)
XN1=FLOAT(N-1)+RR
GMCAV(NB)=(GMCAV(NB)+RR*GMCWB(NB,N))/XN1
GTAV(NB)=(GTAV(NB)+RR*GTEMP(NB,N))/XN1
DEPTH(NB)=0.
DO 100 K=1,N
RM=1.-RATC(GMCWB(NB,K))*(SM(NB,K)-GMCWB(NB,K))
DEPLAY(NB,K)=DEPLAY(NB,K)*RM
DEPTH(NB)=DEPTH(NB)+DEPLAY(NB,K)
SM(NB,K)=CMCWB(NB,K)
100 CONTINUE
ACBU(NB)=DEPTH(NB)*ALFA(NB)
75 IF(MSTO.EQ.2.AND.IFAN(NB).EQ.1)RETURN
IF(GMCAV(NB).LT.GMAV.AND.GMCMA(NB).LT.GMAX)GOTO 40
IF(JULDAY.EQ.141)IPASS=0
IF(IPASS.EQ.1)RETURN
IF(JULDAY.EQ.319)RETURN
IF(JULDAY.EQ.349)IPASS=1
IF(GTEMP(NB,N).GT.30.)RETURN
IF(JULDAY.EQ.335)GOTO 38
IF(GMCWB(NB,N).LT.18.)GOTO 50
RETURN
38 IF(GTEMP(NB,N).LT.20.)GOTO 50
IF(GTEMP(NB,N).GT.25.)RETURN
IF(GMCWB(NB,N).LT.20)GOTO 50
RETURN
40 IF(IFILL(NB).GT.99)GOTO 45
   IF(JULDAY.GT.300)GOTO 45
   IF(JULDAY.LE.140)GOTO 45
   RETURN
45 IF(IFILL(NB).GT.0)JODAT(NB)=JULDAY
   IFAN(NB)=0
   IFANON=IFANON-1
   RETURN
50 IFAN(NB)=1
   RETURN
   END

FUNCTION RATC(WB)
   IF(WB.LT.25.)GOTO 60
   RATC=.01
   RETURN
60 IF(WB.LT.20)GOTO 62
   RATC=.013
   RETURN
62 IF(WB.LT.15)GOTO 64
   RATC=.015
   RETURN
64 RATC=.017
   RETURN
   END

SUBROUTINE DRYING(T0,RHO,NB)
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1,DELT,IFILL(6),IFAN(6),IFANON,IFILON,LAYER(6),NO,N,MB,JULDAY
COMMON/BY/GMCDB(6,20),GTEMP(6,20),GSTM(6,20),SM(6,20),
1,GDTMAX(6),GDTR(6,20),GMCAT(6),MAXLAY
COMMON/CN/CFMSF(6),FINC(6),BINH(6),BINBU(6),ACBU(6),TRANS,CAR,MODE
COMMON/DY/GMCHA(6),GMCWH(6),FANHRS(6),GMAV,GMAX,LAYDP(6),JODAT(6)
COMMON/FN/FANCH(6,2,10),AREA(6),FANSB(6),CBU(6),FANKW(6)
1,SUPHT(6),GATV(6),DTR(6,20)
COMMON/ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/TH/DMFI,DMF2,HF1,EMC1,HF2,TF2,IDW,R,E,C
COMMON/BIN/TT1,HH(6,21),RH(6,21)
DATA RHC,EPS/.999,01/
DATA A1,A2,A3,A4,A5,A6/1094.,.57,-.2825,1092.8,4.35,.63347/
EXTERNAL TEN,HFIND
RH1=RHO/100.
PV1=RHI*PS(T0)
HF1=HUM(PV1)
VA1=VA(T0,HF1)
FANHT=FANKW(NB)*.93
IF(SUPHT(NB).GT.100.)GOTO 80
FINC(NB)=FANHT*VA1/(AIR(HF1)*CFMSF(NB)*AREA(NB))+SUPHT(NB)
GOTO 85
FINC(NB)=\((SUPHT(NB)+FANHT)^{\text{val}/(\text{AIR}(HF1)\times CFMSF(NB)\times \text{AREA}(NB))}\)

TF1=TF0+FINC(NB)

R1=\(A6/(CFMSF(NB)\times \text{DELT})\)

RH1=P(HF1)/PS(TF1)

TT1=TF1

HH(NB,1)=HF1

RH(NB,1)=RH1

C

MODE=1 FOR NATURAL EQUILIBRIUM MODEL ONLY.

MODE=2 FOR PROPORTIONAL MIXING WITH MODE 0 & MODEL 5.

MODE=3 FOR MOREY'S MODEL ONLY.

MODE=4 FOR THOMPSON'S COMBINATION MODEL.

MODE=5 FOR MISRA'S THIN LAYER DRYING EQUATION ONLY.

IWET=0 FOR NO ABSORPTION PROCESS.

IWET=1 FOR ABSORPTION PROCESS IN MOREY'S MODEL.

IWET=2 FOR ABSORPTION PROCESS BY MISRA EQUATION.

IWET=3 FOR ABSORPTION PROCESS IN THOMPSON'S EQUILIBRIUM MODEL.

IDW=0

DM2=GMCOD(NB,1)

DO 60 I=1,N

I2=I+1

25 DMF1=GMCDB(NB,I)

R=\(R1^{\text{val}}(TF1,HF1)^{\text{DEPL}}(NB,I)/(1-.01^{\text{DMF1}})\)

GT1=GTEMP(NB,I)

DM0=GMCOD(NB,I)

AIR1=AIR(HF1)

GRNR=GRN(DMF1)^{\text{R}}

C1=GT1-A4

DMF2=DMF1

D=AIR1^{\text{TF1}}+GRNR^GT1

EMC1=EMC(RH1,TF1)

IF(DMF1.GT.EMC1)GOTO 34

IF(IWET.EQ.0)GOTO 32

24 IDW=2

EMC2=EMC(RH1,TF1)

IF(DMF1.GT.EMC2)GOTO 32

IF(IWET.EQ.3)GOTO 28

C=C1

E=D-C\times HF1

XMR1=1

XMR1=XMRISRA(XMR1,TF1,RH1,DELT,CFMSF(NB),DM2)

GOTO 35

28 C=C1

E=D-C\times HF1

IDW=4

30 CALL ROOT(DMF2,RH1,HFIND,.001)

31 HF1=HF2

DMF1=DMF2

IF(RH1.GT.RHC)RH1=RHC
GOTO 38
32 IDW=0
33 IF(TF1.EQ.GT1)GOTO 38
   TF1=(AIR1*TF1+GRNR*GT1)/(AIR1+GRNR)
   GOTO 38
34 IDW=1
   DELL=-(A1-A2*GT1)*A5*EXP(A3*DMF1)
   C=C1+DELL
   E=D-C*HF1
   IF(MODE.EQ.1)GOTO 30
40 DELM=DMO-EMC1
   IF(DMF1.GT.DMO)DELM=DMF1-EMC1
   XMR1=(DMF1-EMC1)/DELM
   IF(MODE.EQ.3.OR.MODE.EQ.7)GOTO 200
   IF(MODE.EQ.2)GOTO 50
   IF(MODE.NE.4)GOTO 55
   IF(CBU(NB).GT.2.)GOTO 300
50 IF(MODE.EQ.5)GOTO 300
55 IF(MODE.EQ.5)GOTO 300
50 IF(XMR1.LT..12)GOTO 300
   CALL ROOT(DMF2,RH1,HFIND,.001)
   SMR1=ABS(DMF2-DMF1)
   IF(SMR1.LT..0001)GOTO 31
   DMF3=DELM*XMR1+EMC1
   IF(MODE.EQ.7)DMF3=(DMF3+DMF1)/2.
   SMR2=ABS(DMF3-DMF1)
   IF(SMR1.LT.SMR2)GOTO 31
200 CALL ROOT(DMF2,RH1,HFIND,.001)
210 SMR1=ABS(DMF2-DMF1)
   IF(SMR1.LT..0001)GOTO 31
   DMF3=DELM*XMR1+EMC1
   IF(MODE.EQ.7)DMF3=(DMF3+DMF1)/2.
   SMR2=ABS(DMF3-DMF1)
   IF(SMR1.LT.SMR2)GOTO 31
250 DMF2=DMF3
GOTO 36
300 XMR1=XMR1*TF1,RH1,DELT,CFMSF(NB),DMO)
35 DMF2=DMF1+EMC1
36 HF1=HF1+.01*R*(DMF1-DMF2)
   TF1=TEM2(HF1)
   DMF1=DMF2
   RH1=P(HF1)/PS(TF1)
   IF(RH1.LE.RHC)GOTO 38
37 C=TF1-A4
   D=(AIR(HF1)+GRN(DMF1)*R)*TF1
\[ E = D - C^*HF1 \]

CALL ROOT(TF1, HF1, TEM, EPS)

DMF1 = DMF2

IDW = IDW + 2

RH1 = RHC

38

HH(NB, I2) = HF1

RH(NB, I2) = RH1

GTEMP(NB, I) = TF1

GMCDB(NB, I) = DMF1

GMCWB(NB, I) = DMF1 * 100. / (100. + DMF1)

60 CONTINUE

RETURN

END

C

FUNCTION VA(T, H)

DATA R, D, T460, ATM/53.35, 144., 459.69, 14.696/

TO = T + T460

PV = P(H)

VA = R*T0 / (D*(ATM - PV))

RETURN

END

C

FUNCTION XMISRA(XMR, T, RH, DELT, V, DM0)

DIMENSION C(5), D(5)

COMMON/TH/DMF1, DMF2, HF1, EMC1, HF2, TF2, IDW, R, E, CC

DATA C, D/7.1735, 1.2793, .0007, .0811, .0078, 8.5122, 1.2178, .0864,

1 2.1876, 1.67/

IF(IDW .EQ. 2) GOTO 50

XK = EXP(-C(1) + C(2)*ALOG(T) + C(3)*V)

XN = C(4)*ALOG(RH*100.) + C(5)*DM0

GOTO 100

50

XK = EXP(-D(1) + D(2)*ALOG(T) + D(3)*DM0)

XN = D(4) - D(5)*RH

100

TEQ = (-ALOG(XMR)/XK)**(1./XN)

TEQ = TEQ + DELT

XMISRA = EXP(-XK*TEQ**XN)

RETURN

END

C

FUNCTION AIR(H)

DATA A, B/.245, .45/

AIR = A + B*H

RETURN

END

C

FUNCTION GRN(WB)

DATA A, B, C/.35, .0085, 100. /

GRN = A + B*WB*C/(C + WB)

RETURN

END
FUNCTION PS(T)
DATA A,B,C,D,E,F,G/54.6329,12301.69,5.16923,23.3924,11286.65,1.46057,459.69/
TB=T+G
IF(T-32.)1,2,2
1 PS=EXP(D-E/TB-F*ALOG(TB))
RETURN
2 PS=EXP(A-B/TB-C*ALOG(TB))
RETURN
END

FUNCTION HUM(P)
DATA ATM,A/14.696,.6219/
HUM=A*P/(ATM-P)
RETURN
END

FUNCTION P(H)
DATA A,B/23.63,1.608/
P=A*H/(1.+B*H)
RETURN
END

FUNCTION EMC(RH,T)
COMMON/TH/DMF1,DMF2,HF1,EMC1,HF2,TF2,IDW,R,E,CC
THOMPSON'S EQUATION
DATA RHC,A,B,C/.999,3.62E-5,1.045E-4,.5814/
RH0=RH
IF(RH0.GT.RHC)RH0=RHC
T0=T+50.
IF(T0.LT.70.)T0=70.
IF(IDW.EQ.2.AND.RH0.LT..99)GOTO 10
EMC=SQR((ALOG(1.-RH0)/A*T0))
IF(IDW.EQ.0)RETURN
RETURN
10 EMC=(-ALOG(1.-RH0)/(B*T0))**C
RETURN
END

FUNCTION HFIND(DMF,RH)
COMMON/TH/DMF1,DMF2,HF1,EMC1,HF2,TF2,IDW,R,E,C
DATA RHC/.999/
HF2=HF1+(DMF1-DMF)*R/100.
DMF2=DMF
IF(HF2.LT.0.)HF2=.00005
TF2=TEM2(HF2)
PSV=PS(TF2)
PV=P(HF2)
RH=PV/PSV
IF(RH.GT.RHC) RH=RHC
HFIND=EMC(RH,TF2)
DMF2=HFIND
RETURN
END

FUNCTION TEM(T,H)
COMMON/TH/DMFl,DMF2,HFl,EMCl,HF2,TF2,IDW,R,E,C
PS1=PS(T)
H=HUM(PS1)
DMF2=DMFl+(HFl-H)/R*100.
TEM=TEM2(H)
RETURN
END

FUNCTION TEM2(H)
COMMON/TH/DMFl,DMF2,HFl,EMCl,HF2,TF2,IDW,R,E,C
TEM2=(E+H*C)/(AIR(H)+GRN(DMF2)*R)
TF2=TEM2
RETURN
END

SUBROUTINE STORE(NB,TB)
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1 ,DELT,IFILL(6),IFAN(6),IFANON,IFILON,LAYER(6),NO,N,MB,JULDAY
COMMON/FN/X(126),FANSP(6),CBU(6),F(6),SUPHT(6),GTAV(6),DTR(6,20)
COMMON/BY/GMCDB(6,20),GMCOD(6,20),GTEMP(6,20),GSTM(6,20),SM(6,20),
1 GDTMAX(6),GDTR(6,20),GMCN(6),MAXLAY
COMMON/IN/MSTO,JER(6),TDTR,TLOW,BCFM,RHOFF,TMOFF,JRHDY,KC,ICODE
COMMON/BIN/TTL,RH(6,21)
DIMENSION C(9)
DATA A1,A2,A3,F1/.0883,.006,.00102,67.72/
DATA C/.103,1.53,.00845,1.558,128.76,.078,32.3,.058,.0102/
TIME=DELT
GMAX=0.
DO 80 I=1,N
T=GTEMP(NB,I)
DB=GMCDB(NB,I)
WB=GMCWB(NB,I)
DM=1.
XMT=C(1)*(EXP(455./DB**C(2))-C(3)*DB+C(4))
IF(T-60.)10,20,20
10 XMT=C(5)*EXP(-C(6)*T)
GOTO 70
20 XMT=C(7)*EXP(-C(8)*T)
IF(WB-19.)70,70,40
40 IF(WB-28.)60,60,50
60 XMT=XMT+(WB-19.)*.01*EXP(C(9)*T-60.))
GOTO 70
206

\[ \text{XMT} = \text{XMT} + \cdot 09 \times \text{EXP}(C(9) \times (T - 60.)) \]

\[ \text{SAFES} = \text{XMT} \times \text{XMT} \times \text{DM} \]

\[ \text{GSTM}(N, B, I) = \text{GSTM}(N, B, I) + \text{TIME} / \text{SAFES} \]

\[ \text{GDTR}(N, B, I) = A1 \times (\text{EXP}(A2 \times \text{GSTM}(N, B, I)) - 1.) + A3 \times \text{GSTM}(N, B, I) \]

\[ \text{IF} (\text{GDTR}(N, B, I) \geq \text{GDIMAX}(N, B)) \]

\[ \text{GDTRMAX}(N, B) = \text{GDTR}(N, B, I) \]

\[ \text{IF} (\text{MSTO} \leq 2) \text{GOTO} 80 \]

\[ \text{DTRAT} = \text{GDTR}(N, B, I) - \text{DTR}(N, B, I) \]

\[ \text{IF} (\text{DTRAT} \leq 0.) \text{GOTO} 79 \]

\[ \text{GTEMP}(N, B, I) = \text{GTEMP}(N, B, I) + F1 \times \text{DTRAT} / \text{GRN} (\text{GMCWB}(N, B, I)) \]

\[ \text{GMCDB}(N, B, I) = \text{GMCDB}(N, B, I) + 0.6 \times \text{DTRAT} \]

\[ \text{GMCWB}(N, B, I) = \text{GMCDB}(N, B, I) \times 100. / (100. + \text{GMCDB}(N, B, I)) \]

\[ \text{DTR}(N, B, I) = \text{GDTR}(N, B, I) \]

\[ \text{IF} (T \geq \text{GDTMAX}) \text{GDTMAX} = T \]

\[ \text{IF} (\text{JULDAY} \lt 350. \text{AND} \text{JULDAY} \gt 91) \text{RETURN} \]

\[ \text{IF} (\text{MSTO} \lt 2) \text{RETURN} \]

\[ \text{IF} (\text{GTMAX} \gt \text{TB} + 5.) \text{RETURN} \]

\[ \text{IF} (\text{JER}(N) \neq 0) \text{JER}(N) = 1 \text{RETURN} \]

\[ \text{SUBROUTINE PRINT2(TB, TRH, IPRINT)} \]

\[ \text{COMMON/GN/GMCWB(6, 20), DEPLAY(6, 21), DEPTH(6), ALFA(6), WGD(6)} \]

\[ \text{1}, \text{DELT, IFILL(6), IFAN(6), IFANON, IFILON, LAYER(6), NO, N, MB, JULDAY} \]

\[ \text{COMMON/CN/CFMSF(6), FINC(6), BINH(6), BINBU(6), ACBU(6), TRANS, CAR, MODE} \]

\[ \text{COMMON/FN/\times(126), FANSP(6), CBU(6), F(6), SUPHT(6), GTAV(6), DTR(6, 20)} \]

\[ \text{COMMON/BN/GMCD(6, 20), GMCDB(6, 20), GTEMP(6, 20), GSTM(6, 20), SM(6, 20), 1} \]

\[ \text{GDTMAX(6), DTR(6, 20), GMCAV(6), MAXLAY} \]

\[ \text{COMMON/DY/GMCDA(6), CURKWH(6), FANHRS(6), GMAY, GMAX, LAYDF(6), JODAT(6)} \]

\[ \text{COMMON/IN/MSTO, JER(6), DTR(6), TOL(6, 20), BC, RHOFF, THOFF, JHRDY, KC, ICOD} \]

\[ \text{COMMON/ALL/IPFLD, IFLD(30, 6), IDAY(4), FRZMST, IWET, MAINC} \]

\[ \text{COMMON/BIN/TTI, HH(6, 21), RH(6, 21)} \]

\[ \text{DIMENSION HIGH(20), MX(14)} \]

\[ \text{DATA TEN, T4/10.}, \text{1000.0} / \]

\[ \text{IF(IPRINT \geq 4) RETURN} \]

\[ \text{IF(\text{JULDAY} \cdot \text{GE} \cdot \text{JRHDA}) \text{RETURN}} \]

\[ \text{IF(\text{JULDAY} \cdot \text{小于} \cdot 140) \text{RETURN}} \]

\[ \text{83 IF(\text{TB} \cdot \text{LT} \cdot \text{TLOW}) \text{RETURN}} \]

\[ \text{IF(IPRINT \geq 8) \text{GOTO} 95} \]

\[ \text{IF(\text{KC} \cdot \text{EQ} \cdot 0) \text{GOTO} 100} \]

\[ \text{KC=KC+1} \]

\[ \text{IF(\text{KC} \cdot \text{GT} \cdot \text{IPRINT}) \text{KC=0}} \]

\[ \text{RETURN} \]

\[ \text{100 KC=KC+1} \]

\[ \text{95 DO 400 NB=1, MB} \]

\[ \text{IF(IFAN(NB) \cdot \text{EQ} \cdot 0) \text{GOTO} 400} \]
N=LAYER(NB)
RR=DEPLAY(NB,N)/DEPLAY(NB,21)
SUMD=GDT(NB,1)
HIGH(1)=DEPLAY(NB,1)
IF(N.EQ.1)GOT0 97
DO 111 JJ=2,N
HIGH(JJ)=HIGH(JJ-1)+DEPLAY(NB,JJ)
111 SUMD=SUMD+GDTR(NB,JJ)
97 SUMD=(SUMD-(1.-RR)*GDTR(NB,N))/(FLOAT(N)-1.+RR)
XMDB=GMCAV(NB)*100./(100.-GMCAV(NB))
IF(IPRINT.EQ.7)GOT0 200
MX(1)=ACB(NB)*TEN
MX(3)=CBU(NB)*TEN
MX(2)=DEPTH(NB)*TEN
MX(4)=TB*TEN
MX(5)=THR*TEN
MX(6)=GMDB(NB,1)*TEN
MX(7)=GHCAV(NB)*TEN
MX(8)=GMDB(NB,N)*TEN
MX(9)=GDT(NB,N)*T4
MX(10)=SMD*T4
MX(11)=GTM(NB,N)*T4
MX(12)=GTEM(NB,1)*TEN
MX(13)=GT(NB,1)*TEN
MX(14)=GTM(NB,N)*TEN
WRITE(NB,2040)IDAY,ICODE,NB,LAYD(NB),N,IFAN(NB),MX
2040 FORMAT(3I2,' /M3,1X,I6,' B' ,11,IX,12//',12,' F',I1,' BU',I6,' /
1 I3,' CB',I3,' A',I3,' /',I3,1X.3(I3,1X),3I5,1X.3(I3,1X))
IF(IPRINT.EQ.6)GOT0 400
200 NN=6
210 N2=N+1
RRH1=RH(NB,1)*100.
IF(IPRINT.EQ.4)GOT0 300
WRITE(NN,2000)IDAY,ICODE,NB,LAYD(NB),N,IFAN(NB),ACB(NB),CBU(NB), *
 CFM/BU',F7.1,' CFM/SF=',F4.1,' IN.W.=',F5.2,' % MCDB=',F4.1, '% TEMP=',F6.4,
 ' (INLET AIR: RH=',F4.1,' % T=', F5.1,' F H=',F6.4,')
2000 FORMAT(1X,'DATE:',3(I2,.'/'),I3,' BIN=',I2,' DRYFRNT=',I2,' FAN=', 
 * I1,' BUSHEL=',F7.1,' CFM/BU=',F4.1,' % MCDB=',F4.1, '% TEMP=',F6.4,
 * F5.2,' FRESH AIR: T=',F5.1,' RH=', F4.1, '%/ ' AVERAGE: MCDB=', 
 * F4.1,' % MCDB=',F4.1, '% TEMP=',F6.4,' DTR=',F6.4, 
 * ' (INLET AIR: RH=',F4.1,' % T=', F5.1,' F H=',F6.4,')')
2019 FORMAT(1X,'LAYER NO.',20(2X,I2,2X))
2020 FORMAT(1X,'DEPTH,FT.',20(F5.2,1X))
2022 FORMAT(1X,'GRAIN T.',1X,20(F5.1,1X))
2023 FORMAT(1X,'MCDB,%',1X,20(F5.2,1X))
2024 FORMAT(1X,'MCWB,%',3X,20(F5.2,1X))
2025 FORMAT(1X,'REL HUM',2X,20(F5.3,1X))
2026 FORMAT(1X,'ABS HUM',2X,20(F6.4,1X))
2027 FORMAT(1X,'SPOILAGE',1X,20(F6.4,1X))
2028 FORMAT(1X,'DATE:',3(12,'/'),13,' B',12,' DF',12,' BU',F7.1,
1 ' CFMBU',F4.1,' AIR:',F5.1,' F/',F4.1,'% MCWB=',F4.1,
2 '% DTR=',F6.4)
GOTO 400
300 WRITE (NN,2028)IDAY,NB,LAYDF(NB),ACBU(NB),CBU(NB),TB,TRH,
* GMCAV(NB),GDMAX(NB)
WRITE(NN,2024)(GMCWB(NB,JK),JK=1,N)
WRITE(NN,2025)(RH(NB,JK),JK=1,N)
400 CONTINUE
RETURN
END

SUBROUTINE INFO(DB,RH,K)
COMMON/GN/GMCWB(6,20),DEPLAY(6,21),DEPTH(6),ALFA(6),WGD(6)
1 ,DELT,IFILL(6),IFAN(6),IFAN0N(6),IFIL0N(6),LAYER(6),NB,N,MB,JULDAY
COMMON/CN/CFMSF(6),FINC(6),BINH(6),BINBU(6),ACBU(6),TRANS,CAR,MODE
COMMON/CF/RES(6),FILL(6),HGBU,HGMC,INDAT(6),IC,XLOAD(6),ATBU(6)
COMMON/CY/GMCDB(6,20),GTEMP(6,20),GSTM(6,20),SH(6,20),
1 GDMAX(6),GDTM(6,20),GMCOD(6,20),GMCMA(6)
COMMON/FN/FANCH(6,2,10),AREA(6),FANSF(6),CBU(6),FANKW(6)
1 ,SUPHT(6),GTAV(6),DTR(6,20)
COMMON/DT/GHCMA(6),CUNKH(6),FANHRS(6),GHAV,GMAX,LAYDF(6),JODAT(6)
COMMON/IN/HSTO,IER(6),TDTR,TLOW,BCFM,RH0FF,TH0FF,JHRDYS,HC,ICODE
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IBET,MAINC
DIMENSION NAME(4,4),LAST(3),BINDA(6),LB(2,6),GGG(6),NG(6),
* ENRG(6),SHRIN(6),GI(6),GZ(6)
DATA NAME/'WEEK','LY ','REPO','RT ','FALL',' SHU','T DO','WN ','
1 'SPRI','NG S','HUT ','DOWN','FINA','L SH','UT D','OWN '
* ,LAST,BLB,LBL'/ OFF',' ON',' NOT ','USED',' '/
IF(K.EQ.0)GOTO 10
IF(K.EQ.1)GOTO 20
IF(K.GE.6)RETURN
GOTO 30
10 READ(5,50)NB,HSTO,MODE,IBET
50 FORMAT(1X,IL,3I2)
READ(5,200)BCFM,GHAV,GMAX,TRANS,THOFF,CAR,XIN,IC,MCLAY,TLOW,TDTR,
1 RHOFF,JHRDYS
IF(MCLAY.GT.20)MCLAY=20
ICODE=MSTO*100+MODE*10+IBET+IC*10000
200 FORMAT(F6.4,6F6.1,2I2,3F5.1,13)
DO 12 I=1,MB
READ(5,100)BINDA(I),BINH(I),FANKW(I),SUPHT(I),((FANCH(I,J,KK),
 1 KK=1,10),J=1,2)
100 FORMAT(1X,2F5.2,F4.1,F5.2,10F5.1/10F5.0)
12 CONTINUE
DO 14 I=1,6
IF(I.GT.MB)GOTO 13
AREA(I)=BINDA(I)*BINDA(I)*.7854
DEPLAY(I,21)=BINH(I)/FLOAT(MAXLAY)
ALFA(I)=AREA(I)/1.245
BINBU(I)=ALFA(I)*BINH(I)
XLOAD(I)=XIN
IF(XIN.GT.10)XLOAD(I)=XIN/ALFA(NB)
LB(1,I)=LB3
LB(2,I)=LB3
GOTO 14
13 AREA(I)=0.
DEPLAY(I,21)=0.
BINBU(I)=0.
ENRG(I)=0.
BINH(I)=0.
NG(I)=1
GGG(I)=0.
BINDA(I)=0.
FANKW(I)=0.
LB(1,I)=LB1
LB(2,I)=LB2
SUPHT(I)=0.
DO 9 19=1,2
DO 9 J9=1,10
FANCH(I,I9,J9)=0.
9 CONTINUE
14 CONTINUE
20 DO 25 I=1,6
IFAN(I)=0
JER(I)=0
IFILL(I)=0
DEPTH(I)=0
LAYER(I)=1
CFMSF(I)=0.
CBU(I)=0.
FANHRS(I)=0.
FANSP(I)=0.
FINC(I)=0.
LAYDF(I)=1
GDTMAX(I)=0.
CUMKMH(I)=0.
ACBU(I)=0.
ATBU(I)=0.
JODAT(I)=0.
210

INDAT(I)=0
FILL(I)=0.
GMCA(I)=0.
WGD(I)=0.
RES(I)=0.
GMCAV(I)=0.
DO 24 J=1,20
GMCDB(I,J)=0.
DTR(I,J)=0.
SM(I,J)=0.
DEPLAY(I,J)=0.
GMCWB(I,J)=0.
GMCOD(I,J)=0.
GTEMP(I,J)=0.
24 GDTR(I,J)=0.
25 CONTINUE
M=1
IFANON=0
IFILON=0
IF(K.EQ.1)RETURN
WRITE (6,700) (1,1=1,6),BINDA,BINH,BINBU,AREA,LB,FANKW,SUPHT,
1 (((FANCH(I0,J0,K0),J0=1,2),I0=1,6),K0=1,10)
IF(MSTO.EQ.0)WRITE(6,702)
IF(MSTO.EQ.1)WRITE(6,703)
IF(MSTO.EQ.2)WRITE(6,701)TDTR,RHOFF,TMOFF
WRITE(6,704)ICODE
GOTO 630
700 FORMAT('1M2X,12('*')/13X,'*MOX,'*'/13X,'*',' BIN DATA '*, '*
1 /13X,'*1',10X,'*/13X,'**//5X,6(13X,'*1',6X)/5X,6(12X,'*1',
2 5X)/5X,6(11X,'*1',4X)/5X,6(10X,'*1',5X,'*',3X)/5X,6(9X,'*1',
3 ' )/5X,6(7X,'**DIAMETER: **')/5X,6(7X,,'**F7.1,'** FT ', '**')/5X,
5 6(7X,,'**11X, '**)//5X,6(7X,,'**F7.1, '** FT ', '**')/5X,
7 7X,,'**F8.0, '** BU.**)/5X,6(7X,,'**F7.1, '** AREA : '*, '5X,
* **)/5X,6(7X,,'**F7.1, '** SQFT**)/
8 2(5X,6(7X,,'**11X, '**)//5X,6(7X,,'**11X,2X4,2X, '*')/2
9 (5X,6(7X,,'**11X, '**)//5X,6(1X,7('**)//5X,6(' =
1 ,5X,,'/HP',',F5.1,' 'KW *')/5X,6(' = FAN /HEAT ADDED: **')/5X,6(' =
2 5X,,'',F6.0, 'B/MIN**')/5X,6(1X,19('**))/5X,6(' FAN DATA: '*,10X)/5X
3 ,6(1X, 'INCHES',5X, 'CFM',5X)/5X,6(1X,6('**))/5X,6(' =',5X,','5X,','5X,,'**19( ='))/10(5X,6(
4 2X,F3.0,3X,F0.0,4X)//5X,6(1X,19(' =')))
701 FORMAT('/5X,'THE AERATION PROCESS IS DETERMINED BY THE SIMULATION',
4 ' PROGRAM, BUT THE FOLLOWING CONSTANTS ARE SET AS FOLLOW:'/5X,
5 ' 1. THE MAXIMUM ALLOWABLE GRAIN TEMPERATURE= ',F5.1,' ', F.,'/5X,
6 ' 2. THE MAXIMUM ALLOWABLE AIR RELATIVE HUMIDITY= ',F5.1,' %,'/5X,
7 ' 3. THE ALLOWABLE AERATION TIME PER DAY= ',F5.1,' HOURS.'/)
702 FORMAT('/5X,'THE AERATION PROCESS DURING STORAGE OR WINTER MONTH ',
1'IS DETERMINED BY FARMERS.'*/5X,'ALL GRAIN TEMPERATURE AND MOISTU'
2, 'RE ARE ASSUMED THE SAME AS THE TIME BINS ARE SHUT OFF.'/
703 FORMAT(5X,'THE AERATION PROCESS IS IGNORED, BUT THE GRAIN MOISTU'
1, 'RE AND TEMPERATURE DURING STORAGE ARE ADJUSTED'/5X,'ACCORDING'
2 , 'TO THE RESPIRATION AND DECOMPOSITION OF GRAIN MATTER.'/)
704 FORMAT(5X,'THE BIN FILLING STRATEGY IS: (CODE=',17,')'
30 WRITE(6,300)BCFM,MAXLAY,IDAY,(NAME(I,K-1),I=1,4),DELT,DB,TRANS,
1RH,CAR,TLOW,GMAX,GMAV,(I,1=1,6),BINH,BINDA,BINBU
300 FORMAT('l',41X,45('*')/42X,'**',41X,'**'/42X,'**',5X,'REPORT ',
1 'ON BIN DRYING AND STORAGE',4X,'**'/42X,'**'/42X,'**'/42X,45('**')
* .28X, 'BCFM: ',F9.3/109X,'MAX. LAYER:',I5/3X,'* DATE:',I3,'-',I2,
2 '-',I2,'/',I3,'35X,('.,A4,.',')/30X,'TIME INTERVAL:',F6.0,'HRS.',
* /3X,'* AIR TEMP:',F8.1,'F',81X,'CONVEYER CAPAC.:',F6.0,'BU/HR'
3 /3X,'* HUMIDITY:',F8.1,'%78X,'MIN. HANDLING LOAD:',F6.0,'BU.'
* /3X,'* CUTOFF TEMP:',F5.1,'F',71X,
* 'M.C. CRITERIA:MAX.=',F5.1,'%;AVE.=',F4.1,'%'/1X,* BIN NO. '
4 ,8X,6(1X,7('**')/1X,I1,1X,7('**')/1X)/3X,'BIN',12X,6(1X,17('-'
5 ),1X)/3X,3('=')/5X,'HEIGHT,FT',4X,6(7X,F4.1,8X)/5X,'DIAMETER,FT'
6 ,2X,6(7X,F4.1,8X)/5X,'CAPACITY,BU',2X,6(3X,F8.1,8X)/)
DO 60 I=1,MB
NN=_LAYER(I)
ENRG(I)=0.
DO 160 J=1,NN
ENRG(I)=ENRG(I)+(GMCOD(I,J)-GMCDB(I,J))*DEPLAY(I,J)
160 CONTINUE
ENRG(I)=CUMKWH(I)*341300./(ENRG(I)*ALFA(I)*47.32)
NG(I)=FLOAT(LAYER(I))/2.+5
SHRIN(I)=(1.-ACBU(I)/ATBU(I))*100.
G1(I)=DEPLAY(I,21)*ALFA(I)
G2(I)=DEPLAY(I,NN)*ALFA(I)
60 GGG(I)=GMCOD(I,1)*100./(100.+GMCOD(I,1))
WRITE(6,400)(LAST(IFAN(I)+l),1=1,6),FANKW,CFMSF,CBU,FANSP,FINC
* ,CUMKWH,FANHRS,ENRG
400 FORMAT(3X,'FAN',12X,6(1X,17('-'),1X)/3X,6(7X,F4.1,8X)/5X,'KW',11X,6(7X,F4.1,8X)/5X,'CFM/FT',7X,6(7X,
2 F4.1,8X)/5X,'CFM/BU',7X,6(7X,F4.1,8X)/5X,'PRESSURE,IN',2X,6(6X
3 ,F6.2,7X)/5X,'TEMP.RISE,F',2X,6(7X,F4.1,8X)/5X,'KWH',10X,6(3X,
4 F8.1,8X)/5X,'FAN HRS.',5X,6(3X,F8.1,8X)/5X,'BTU/LB WATER ',
5 6(3X,F9.2,7X)/)
WRITE(6,500 )INDAT, GGG, GMCMA, ATBU, DEPTH, LAYER,LAYDF,
* ,G1,G2,SHRIN ,IFILL ,JODAT
500 FORMAT(3X,'GRAIN',10X,6(1X,17('-'),1X)/3X,5('=',)/5X,'DATE IN',6X
1 ,6(6X,I3,10X)/5X,'INITI. MCB%',1X,6(7X,F4.1,8X)/5X,
* , 'MAX. MCB%',3X,6(3X,F8.1,8X)/5X,'TOTAL BU.'
2 ,4X,6(3X,F8.1,8X)/5X,'ACT.DEPTH,FT',1X,6(7X,F4.1,8X)/5X,'LAYERS'
* ,7X,6(6X,I3,10X)/5X,'FRONT LAYER',2X,6(6X,I3,10X)/
3 5X,'BU./LAYER',4X,6(3X,F8.1,8X)/5X,'TOP LAYER',
4 ,1X,6(3X,F8.1,8X)/5X,'SHRINKAGE',4X,6(5X,F5.2,2,'%8/8X)/5X,
5 'FILLING',6X,6(6X,I3, '%8)/5X,'DATE STOP',3X,6(6X,I3,10X)/)
WRITE(6,600)GMCWB(I,1),GMCAV(I),GMCWB(I,LAYER(I)),I=1,6,
1 (GTEMP(I,1),GTEMP(I,NG(I)),GTEMP(I,LAYER(I)),I=1,6),
2 \((\text{GDTR}(I,1),\text{GDTR}(I,\text{NG}(I)),\text{GDTMAX}(I),I=1,6)\),
3 \((\text{GSTM}(I,1),\text{GSTM}(I,\text{NG}(I)),\text{GSTM}(I,\text{LAYER}(I)),I=1,6),\text{ICODE}\)

600 \text{FORMAT}(3X,'\text{OTHERS'},9X,6(1X,17(' '),1X)/3X,6('=',1),9X,6(2X,
1 'BOT.',2X,'MED.',2X,'TOP ',1X)/18X,6(3(2X, '.',1X))1X)/5X,
2 'MOISTURE, %HB',1X,6(3(2X,F4.1),1X)/5X,'GRAIN TEMP., F',6(3(2X,
3 F4.1),1X)/5X,'DET. RATE, %',2X,6(3(1X,F5.3),1X)
4 /5X,'EQ. STO. HRS.',6(3(1X,F5.0),1X)/132('*')/
5 3X,'BIN-FILLING MANAGEMENT METHOD: (CODE=',16,')'/3X,30('=',1)
630 \text{IF}(\text{XIN.GT.1..AND.ICODE.GT.1})\text{WRITE}(6,657)(\text{XLOAD}(I),I=1,\text{MB})
657 \text{FORMAT}(5X, 'THE INPUT QUANTA FOR EACH BIN ASSIGNED(FT.)=',
1 6(3X,F4.1))
IF(ICODE.EQ.1)\text{GOTO 641}
IF(ICODE.EQ.2)\text{GOTO 642}
IF(ICODE.EQ.3)\text{GOTO 643}
IF(ICODE.EQ.4)\text{GOTO 644}
IF(ICODE.EQ.5)\text{GOTO 645}
\text{WRITE}(6,656)\text{MB}
\text{RETURN}
641 \text{WRITE}(6,651)\text{MB}
\text{RETURN}
642 \text{WRITE}(6,652)\text{MB}
\text{RETURN}
643 \text{WRITE}(6,653)\text{MB}
\text{RETURN}
644 \text{WRITE}(6,654)\text{MB}
\text{RETURN}
645 \text{WRITE}(6,655)\text{MB}
\text{RETURN}
651 \text{FORMAT}(5X, 'CONTROLLED FILLING ACCORDING TO THE DRYING FRONT,'
1 * ',I3, ' BINS USED. ')
652 \text{FORMAT}(5X, 'LAYER FILLING, FILLING STARTS AS DRYING FRONT PASSES'
1 ',THROUGH HALF GRAIN DEPTH;',I3, ' BINS USED.')
653 \text{FORMAT}(5X, 'LAYER FILLING, FILLING STARTS AS DRYING FRONT PASSES'
1 * ',THROUGH THE GRAIN DEPTH;',I3, ' BINS USED.')
654 \text{FORMAT}(5X, 'DAILY FILLING WITH VARIABLE DEPTH;',I3, ' BINS USED.')
655 \text{FORMAT}(5X, 'FILLING EVERY OTHER DAY WITH FIXED DEPTH(2 FT);'
1 ',I3, ' BINS USED.')
656 \text{FORMAT}(5X, 'SINGLE FULL BIN FILLING;',I3, ' BINS USED.')
\text{END}
C
\text{SUBROUTINE PLANT(JULDAY,WRKRRS,IST,IZR,YLDDU)COMMON /ALL/IPFLD,I5LD(30,6),IDAY(4),FRZMST,FRSRT,MAINC}
\text{COMMON/PLT1/IPLIST(5,2),PLTACR,PLFIL(30,7),S4FIL(30)}
1 \text{/PLT2/PLTRAT,ACPLT(5),IPLDTY(4),S1FIL(30),}
2 \text{VTYGD(3),YLDPR(20),YLDPLT(3,3)}
\text{TIME=WRKRRS}
40 \text{ACRES=PLTRAT\*TIME}
\text{IF(ACPLT(1ST).LE.0.0)RETURN}
\text{IF(ACRES.GR.AT.ACPLT(I))GO TO 200}
\text{ACPLT(1ST)=ACPLT(I).LE.ACRE}
TIME=0.0
100 IPFLD=IPFLD+1
   IF(IPFLD.GT.30) RETURN
   IFLD(IPFLD,1)=1
   IFLD(IPFLD,2)=JULDAY
   IF(JULDAY.GT.IPLTDY(2).AND.IPLTST(IST,2).EQ.1)IPLTST(IST,2)=2
   IF(JULDAY.GT.IPLTDY(3)) IPLTST(IST,2)=3
   IFLD(IPFLD,6)=IPLTST(IST,2)
   S4FLD(IPFLD)=CUMDUD+VTYGDU(IPFLTST(IST,2))
   RFLD(IPFLD,1)=ACRES
   RFLD(IPFLD,2)=YLDPOT(IYR)-YLD*10.
   RFLD(IPFLD,3)=0.0
   IF(JULDAY.GT.125)GOTO 101
   GOTO 500
101 IF(JULDAY.GT.135)GOTO 102
   IF(IPFLD(IPFLD,6).EQ.1)RFLD(IPFLD,3)=YLDPLT(1,1)*(JULDAY-125)
   GOTO 500
102 IF(JULDAY.GT.145)GOTO 130
   RFLD(IPFLD,3)=YLDPLT(1,1)*10.+(YLDPLT(1,2)*(JULDAY-135))
   IF(IPFLD(IPFLD,6).EQ.2)RFLD(IPFLD,3)=YLDPLT(2,2)*(JULDAY-135)
   IF(IPFLD(IPFLD,6).EQ.3)RFLD(IPFLD,3)=YLDPLT(3,2)*(JULDAY-135)
   GO TO 500
130 IF(IPFLD(IPFLD,6).EQ.1)RFLD(IPFLD,3)= YLDPLT(1,3)*(JULDAY-145)
   *+(YLDPLT(1,1)+YLDPLT(1,2))*10.
   IF(IPFLD(IPFLD,6).EQ.2)RFLD(IPFLD,3)=YLDPLT(2,2)*10.+YLDPLT(2,3)*
   * (JULDAY-145)
   IF(IPFLD(IPFLD,6).EQ.3)RFLD(IPFLD,3)=YLDPLT(3,2)*10.+YLDPLT(3,3)*
   * (JULDAY-145)
500 PLTACR=PLTACR+ACRES
   IF(TIME.EQ.0.0) RETURN
   IST=IST+1
   IF(IST.GT.5)RETURN
   GO TO 40
200 ACRES=ACPLT(IST)
   RUSE=ACPLT(IST)/PLTRAT
   TIME=TIME-RUSE
   ACPLT(IST)=0.0
   GO TO 100
END
C
C
SUBROUTINE FREEZE(IFRZCT,FRZDMG)
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PLT1/IPLTST(5,2),PLTACR,RFLD(30,7),S4FLD(30)
COMMON/FLD1/IHAR,IHARDY,HARMST,DDMST(5),S3FLD(30),IND(30),DB
INTEGER IFZDAM(30),IYES/' YES'/,INO/' NO./
WRITE(6,1000)IDAY,FRZMST
IFRZCT=1
214

1000 FORMAT(/' FIRST FREEZE OCCURS ON ',3(I2,','),(':','I3,'),*','***',' THE SAFE MOISTURE CONTENT IS UNDER:',F5.1,' %MCWB.***')
1010 FORMAT(' DAMAGE?',4X,30A4)
1020 FORMAT(/)
DO 100 I=1,IPFLD
IF(S3FLD(I).LT.FRZMST) GOTO 50
IFZDAM(I)=YES
RFLD(I,4)=FRZDMG*(S3FLD(I)-FRZMST)*.01*(RFLD(I,2)-RFLD(I,3))
GOTO 100
50 IFZDAM(I)=INO
RFLD(I,4)=0.
CONTINUE
WRITE(6,1010)(IFZDAM(I),1=1,IPFLD )
WRITE(6,1020)
RETURN
END

C
C
SUBROUTINE PRINT1(NYR,HARACR,HARBUL)
COMMON /ALL/IPFLD,IFLD(30,6),IDAY(4),FRZMST,IWET,MAINC
COMMON/PLT1/IPLTST(5,2),PLTACR,RFLD(30,7),S4FLD(30)
INTEGER IVAR(3)
DATA IVAR/'LONG','MED.','SHRT'/
TOTAL=0.
DO 500 1=1,5
500 TOTAL=TOTAL+IPLTST(I,1)
WRITE (6,1002) NYR, TOTAL, PLTACR, HARACR, HARBUL
1002 FORMAT(1',36X,5('**'),'SUMMARY REPORTS ON THE 19',12,' PRODUCT',,1 'ION SEASON',5('**')/40X, 50('**')/40X,'**THE TOTAL FIELD ASSIG',,2 'NED = ',F9.1,' ACRES. **'/40X, '**THE TOTAL FIELD PLANTED = ',,3F9.1,' ACRES. **'/40X, '**THE TOTAL FIELD HARVESTED = ',F9.1,' ACR, 4ES. **'/40X, '**THE TOTAL GRAIN HARVESTED = ',F9.1,' BUSHELS.**'/,5 40X,50('**')/19X,'JULDAY DATE EVENTS'/,11X,31('=',1=')/1X,6 'FIELD CORN PLANT- SILK- MATUR- HARVEST- PLANTED POTENTIAL',7 PLANTING FROST FIELD HARVESTED HARVESTED ACRES LEFT'/,8 1X,'NO. TYPE ING ING ITY ING ITY ACRES YIELD(BU)',3X,'LOSS(BU)'),1 YIELD(BU) MOISTURE,% IN FIELD'/127('=')/)DO 150 I=1,IPFLD
WRITE(6,1004)I,IVAR(IFLD(I,6)),(IFLD(I,J),J=2,5),(RFLD(I,K),, K=1,7),S4FLD(I)
1004 FORMAT(1X,I3,3X,A4,4(I6,1X),4X,7F10.3,F14.3)
CONTINUE
RETURN
END

//
Program Lists for the FLDAY Model

C THIS IS MAIN PROGRAM OF FLDAY MODEL.
//C227F0N JOB U3383,DINSUE
//STEP1 EXEC FORTGC,PARM.FORT='NOSOURCE'
//FORT.SYSLIN DD DSN=F.U3383.WD0BJG,UNIT=DISK,
// SPACE=(1920,(20,10)),DISP=(NEW,CATLG),
// DCD=(RECFM=FB,LRECL=80,BKLSIZE=6160,BUFNO=1)
//FORT.SYSIN DD *

DIMENSION IDATE(4),ITEMP(4),SS(5),SST(5),RN(7),WEEK(7)
COMMON /WDY/IDATE,ITEMP,ICLAY,ICORN,SM(3),FC(3),DRS,DUP,WD,ISNOW
COMMON /EXTA/R1,R2,KC,JC
DATA SST,NT/5*0.,0/
3500 FORMAT(/' YEAR RANGE: FROM 19',I2,' TO 19',I2/' CLAY=',I2,
 1 ' C0RN=',I2,' FC1=',F7.2,' FC2=',F7.2,' FC3=','
* F7.2,' DRS=',F4.1,' DUP=',F4.1,' R1=',F4.2,' R2=',F4.2,
 2X,' ( CODE: KC=',12,' JC=',12,' IC=',12,')'/)
READ(5,3000)IYR,JYR,ICLAY,ICORN,FC,DRS,DUP,R1,R2,KC,JC,IC
3000 FORMAT(2I2,2I1,3F4.2,2F2.1,2F4.2,3I2)
WRITE(6,3500)IYR,JYR,ICLAY,ICORN,FC,DRS,DUP,R1,R2,KC,JC,IC
SM(1)=.2
SM(2)=1.
SM(3)=1.
NYR=IYR-50
1 LYR=50+NYR
WRITE(6,4000) LYR
4000 FORMAT(/' THE YEAR 19',I2//' DATE',7X,'OBSERVED',4X,
 1 ' PREDICTED',3X,'DEVIAITION'/2X,'YR(JULIAN)-MO/D',2X,3(1X,
 2 '(DAYS/WEEK)')/2X,15('='),2X,3(lX,11('='))/*NO DATA=8.0 MEANS',
 3 ' NO DATA AVAILABLE.'//
DO2 1=1,5
2 SS(I)=0.
WD1=0
WDT=-100
N=0
K=0
5 READ(NYR,10,END=100)IDATE,ITEMP,WD,WDPRS,HUM,IFREZ,EQM,GDU,
 1 CUMDU,ISNOW,RAIN,PAN,WDAY
10 FORMAT(3I2,13,4I3,3F3.0,1I,1X,F5.4,F3.0,F5.0,14,F4.2,4X,F4.2,F2.1)
IPAN=10
IF(PAN.EQ.0.)IPAN=0
IF(PAN.EQ.0..OR.KC.EQ.1)PAN=ESPM(ITEMP(3),HUM)
CALL FLDAY(KK,PAN,RAIN)
IND=WD*10.+5
IMB=WD
IWBDS=WDPRS
IHUM=HUM
IEQM=EQM*10000.+5
IGDU=GDU
ICUMDU=CUMDU
IRAIN=RAIN*100.+5
IWDAY=WDAY*10.+5
IF(JC.EQ.1)WRITE(32,11)IDATE,ITEMP,IWB,IWBDP,IHUM,IFREZ,IEQM,IGDU,
1 ICUMDU,ISNOW,IRAIN,IWD,IPAN,IWDAY
11 FORMAT(3I2,I3,4I3,3I3,11,1X,I5,I3,I5,2I4,1X,I2,1X,
14,12)
IF(WDAY.GE.0.)GOTO 15
IF(WDAY.GT.0.)WDT=0.
GOTO 5
15 IF(KK.EQ.0)KK=1
WDT=WDT+WD
K=K+1
RN(K)=RAIN
WEEK(K)=WD
IF(K.EQ.7)GOTO 95
GOTO 5
95 IF(IC.EQ.0)GOTO 94
IF(WDAY.NE.8.)GOTO 94
IF(WDAY.EQ.7.)WDT=7.
IF(WDAY.EQ.0.)WDT=0.
94 DEL=WDT-WDAY
WRITE(1,1600)IDATE(1),IDATE(4),IDATE(2),IDATE(3),WDAY,WDT,DEL,
1 RN,WEEK
1600 FORMAT(2X,12,'(',13,')--',12,'/',I2,3(7X,F4.1),6X,'RAIN=',7F5.2,
1 ' WD=',7F2.0)
IF(WDAY.GE.8.)GOTO 96
CALL SSX(WDAY,WDT,SS,N)
96 WDT=0.
K=0
GOTO 5
100 SUM1=SS(1)-SS(2)
WRITE(6,1700)SS(1),SS(2),SUM1
1700 FORMAT(16X,3(1X,'SUM=',F6.1))
IF(N.LT.20)GOTO 300
CALL REG(SS,AA,BB,RR,N)
CALL PRNTS(N,SS,AA,BB,RR)
DO 200 I=1,5
200 SST(I)=SST(I)+SS(I)
NT=NT+N
WRITE(6,101)
101 FORMAT(//5X,'THE CUMULATIVE ANALYSIS***'//)
CALL REG(SST,AAT,BBT,RRT,NT)
CALL PRNTS(NT,SST,AAT,BBT,RRT)
300 NYR=NYR+1
IF(NYR.GT.JYR-50) STOP
SUBROUTINE FLDAY(KK,PAN,RAIN)
DIMENSION IDATE(4),ITEMP(4)
COMMON /WDY/IDATE,ITEMP,ICORN,SM1,SM2,SM3,FC1,FC2,FC3,
* DRS,DUP,WD1,ISNOW
COMMON /EKTA/R1,R2,KC,JC
IF(KK.NE.0)GOTO 10
1 M32=0
N32=0
ITHAW=0
STO=0
NSW=0
10 JUDAT=IDATE(4)
IF(JUDAT-100)20,20,39
39 IF(JUDAT-273)40,40,20
20 IF(ITEMP(2).LT.32)G0T0 21
N32=N32+1
GOTO 22
21 N32=0
22 IF(ITEMP(1).GE.32)G0T0 23
M32=M32+1
GOTO 24
23 M32=0
24 IF(ISNOW.EQ.0)GOTO 25
NSW=NSW+1
GOTO 30
25 NSW=0
30 IF(ITHAW.EQ.1)GOTO 35
IF(ITEMP(1).LT.20)GOTO 32
IF(M32.GT.2)GOTO 32
IF(NSW.GT.2)GOTO 32
GOTO 29
31 IF(ITHAW.EQ.1)ITHAW=0
29 IF(STO.EQ.0.)GOTO 40
RAIN=RAIN+STO
STO=0.
GOTO 40
32 IF(ITHAW.EQ.0)ITHAW=1
33 IF(RAIN.GT.0.)GOTO 34
IF(ISNOW.GT.2.)GOTO 26
IF(JUDAT.GT.273)GOTO 36
IF(ISNOW.GT.0.)GOTO 26
IF(ITEMP(2).LT.20)GOTO 26
IF(ITEMP(1).LT.32)GOTO 26
36 WD1=1.
RETURN
34 STO=STO+RAIN

26 WD1=0.
RETURN
35 IF(ITEMP(1).GT.70)GOTO 31
   IF(N32.GT.2)GOTO 31
   IF(ITEMP(1).GT.60.AND.ITEMP(2).GT.30)GOTO 31
   IF(RAIN.LT.3)GOTO 33
   IF(ITEMP(1).GE.50)GOTO 31
   IF(ITEMP(2).GT.32)GOTO 31
   GOTO 33
40 IF(JUDAT.GT.158) GOTO 41
   EVP=R1*PAN
   GOTO 75
41 EVP=R2*PAN
74 IF(JUDAT.GT.273)GOTO 75
   ETO=ETO(JUDAT)
   EVP1=PAN*ETO
   PAV=100.*(SM2+SM3)/(FC2+FC3)
   ETS1=ETS(PAV,JUDAT,PAN)
   EVP1=ETS1*EVP1*.30
   GOTO 80
75 EVP1=0.
80 RUN1=RUN(RAIN,JUDAT)
   DEDUT=RUN1-EVP
   SM1=SM1+DEDUT
   SM2=SM2+DEDUT
   IF(SM2.LT.0.)SM2=0.
   IF(SM1.GT.FC1)SM1=FC1
   IF(SM1.LT.0.)SM1=0.
90 SMP1=SM1/FC1
   SMP2=SM2/FC2
   WD1=WDY(ICLAY,RAIN,SMP1,SMP2)
   IF(JUDAT.LT.120.AND.RAIN.GT.0.01)WD1=0.
   SM3=SM3-EVP1
   IF(SMP1.LT.SMP2)SM1=SM1+(SMP2-SMP1)*FC1*DUP
   IF(SM3.LT.0.)SM3=0.
   IF(SM2.GT.FC2)GOTO 91
   IF(SM2.GT.9 ) GOTO 92
   DIFF=-(SM3/FC3-SMP2)*FC2*DUP
   GOTO 89
91 DIFF=(SM2-FC2)*DRS
89 SM3=SM3+DIFF
   SM2=SM2-DIFF
92 IF(SM3.GT.FC3)SM3=SM3-(SM3-FC3)*DRS
   IF(SM3.LT.0.)SM3=0.
   IF(SM3.LT.0.)SM3=0.
RETURN
END
FUNCTION RUN(PTT,IDATE)
DIMENSION TPS(7)
DATA TPS,API,A1,A2,A3,B1,B2,B3/8*0.,.27,.724,.4,.55,.175,.6667/
DATA C0,C1,C2,C3,D1,D2,D3/.65,.766,1.3,.2857,.5,1.5,.35/
IF(PTT.GT.1.)API=API+PTT/2.
IF(PTT.LT..5)GOTO 13
7 IF(PTT.GT.2.)GOTO 8
  R1=(PTT-D1)*A1
  GOTO 3
8 R1=(PTT-2.)*A2+A3
3 IF(API-D2)5,5,9
5 IF(PTT.LT.3.)GOTO 6
  R0=D3+(PTT-3.)*B1
  GOTO 4
6 R0=(PTT-1.)*B2
  IF(PTT.LT.1.)R0=0.
4 RUNOFF=API*(R1-R0)*B3+R0
GOTO 15
9 IF(PTT.LT.1.)GOTO 10
    R5=C0 +(PTT-1.)*C1
    GOTO 12
10 R5=(PTT-D1)*C2
12 RUNOFF=(API-D2)*(R5-R1)*C3+R1
    GOTO 15
13 RUNOFF=0.
15 API=0.
   DO 20 I=2,7
     TPS(I)=TPS(I-1)
20 API=API+TPS(I)/FLOAT(I)
   TPS(1)=PTT/2.
   IF(IDATE.LT.243.AND.PTT.LT.1.)TPS(1)=PTT
31 API=API+TPS(1)
   IF(API.GT.6.)API=6.
RUN=PTT-RUNOFF
RETURN
END

SUBROUTINE PRNTS(N,SS,AA,BB,RR)
COMMON /WDY/IDATE(4),ITEMP(4),IX(2),SM(3),FC(3),DD(3),ISNOW
DIMENSION SS(5)
WRITE(2,1600)IDATE,AA,BB,RR
1600 FORMAT(3I2,I3,'Y =(',F10.6,') + (',F10.6,')*X',' RR= ',F10.6)
WRITE(6,1700)N,SS,AA,BB,RR
1700 FORMAT(/5X,'TOTAL WEEKS=',I5,'SUM OF OBSERVED DAYS (X)=',F10.1
1 /F6X,'SUM OF PREDICTED DAYS (Y)=',F10.1/6X,'SUM SQUARE OF X=',F10.1
2 F10.1/6X,'SUM SQUARE OF Y=',F10.1/6X,'SUM OF PRODUCT X*Y=',F10.1/
3 /F6X,'THE REGRESSION EQUATION:/'16X,'Y =(',F10.6,') + (',F10.6,'*
4 )*X'/'6X,'THE CORRELATION COEFFICIENT=',F10.6)
RETURN
END
SUBROUTINE SSX(X1,X2,SS,N)
DIMENSION SS(5),X(2)
X(1)=X1
X(2)=X2
DO 10 I=1,2
SS(I)=SS(I)+X(I)
SS(I+2)=SS(I+2)+X(I)*X(I)
10 CONTINUE
SS(5)=SS(5)+X(1)*X(2)
N=N+1
RETURN
END

SUBROUTINE REG(SS,AA,BB,RR,N)
DIMENSION SS(5)
Z=FLOAT(N)
SXX1=SS(3)-SS(1)/Z*SS(1)
SYY1=SS(4)-SS(2)/Z*Z*SS(2)
SXN1=SS (5)-SS (1)/Z*Z*SS(2)
BB=SXY1/SXX1
AA=(SS(2)-BB*SS(l))/Z
RR=SXY1/SQRT(SXX1)/SQRT(SYY1)
RETURN
END

FUNCTION ETS(PIAV,IDATE,PAV)
DIMENSION XL(5),JC1(5,3,2),JC2(5,3,2)
DATA JC1/27,8,2,1,0,15,25,21,5,2,11,14,18,15,6,24,26,7,3,3,10,
1 17,16,14,5,6,9,11,15,12/,XL/20.,30.,40.,60.,80./
DATA JC2/340,720,900,935,1000,100,-100,20,670,850,30,-30,-150,-35
1,505,120,80,650,810,810,40,-100,-70,10,550,0,-60,-120,-280,-100/
ID=2
IF(IDATE.LE.213)ID=1
IF(PAN-.20)20,20,10
10 IF(PAN-.30)30,30,40
20 IST=1
GOTO 50
30 IST=2
GOTO 50
40 IST=3
50 DO 100 IE=1,5
IF(PAV.LE.XL(IE))GOTO 200
100 CONTINUE
IE=5
200 CC1=JC1(IE,IST,ID)
CC2=JC2(IE,IST,ID)
ETS=(PAV*CC1+CC2)/1000.
RETURN
END
FUNCTION WKDY(JCLAY,RAIN,SM1,SM2)
DIMENSION AWC(3,2)
DATA AWC/.66,.6,.7,.99,.95,.985/,NR,WD1,WD2,WD3/0,3*0./
AW1=AWC(JCLAY,1)
AW2=AWC(JCLAY,2)
IF(RAIN.GT.0.)GOTO 10
NR=0
GOTO 18
10 NR=NR+1
15 IF(RAIN.GT.20)GOTO 19
18 IF(SM1.GT.AW1)GOTO 30
19 IF(SM2.GT.AW2)GOTO 20
20 IF(SM2.LT.1.)GOTO 35
25 WD=0.
30 IF(SM2.GT.AW2)GOTO 25
35 WD=.5
IF(NR.EQ.0.)GOTO 62
36 IF(WD2+WD.GT.5)GOTO 62
61 WKDY=0.
62 WD2=0.
63 WKDY=1.
64 WKDY=WD
65 WD1=WD
RETURN
END

FUNCTION ETO(IDATE)
DIMENSION C(10),L(6)
DATA L/140,168,202,225,258,265/,K/2/,C/2.14E-3,.07,
* 1.14E-2,-1.49,0.,81,-8.07E-3,2.63,-.026,7.258/
IF(IDATE.LE.L(1).OR.IDATE.GT.L(6))GOTO 40
DO 20 I=K,6
   IF(IDATE.LE.L(I))GOTO 10
20 CONTINUE
10 ETO=C(I*2-3)*IDATE+C(I*2-2)
   K=I
   RETURN
40 ETO=.37
   IF(IDATE.EQ.L(1))K=2
   RETURN
END

C
FUNCTION ESPAN(ITAV,RH)
DIMENSION VAL(6)
DATA VAL/.45,.4,.3,.2,.1,.05/
   IF(ITAV.GT.32)GOTO 5
   FAC=.3
   GOTO 9
5  IF(ITAV.GT.40)GOTO 8
   FAC=.7
   GOTO 9
8  FAC=1.+FLOAT(ITAV-50)*.005
   GOTO 9
9 DO 10 I=40,90,10
   RHL=I
   IF(RH.LT.RHL)GOTO 20
10 CONTINUE
   ESPAN=.05*FAC
   RETURN
20 ESPAN=FAC*VAL(I/10-3)
   RETURN
END

//