Probability curves from simulated drying of wheat with near-ambient air in Manitoba

C.I. KITSON[1], W.E. MUIR[1] and R.N. SINHA[2]

[1]Department of Agricultural Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 2N2; and [2]Agriculture Canada Research Station, 195 Dafoe Road, Winnipeg, MB, Canada R3T 2M9. *Received 23 May 1989; accepted 17 July 1990.*

Kitson, C.I., Muir, W.E. and Sinha, R.N. 1991. **Probability curves from simulated drying of wheat with near-ambient air in Manitoba.** Can. Agric. Eng. 33:067-071. Probability curves for the drying of wheat in Manitoba with air at near-ambient conditions based on 33 years of historic weather data were generated to assist designers and operators of systems. Fan size, energy consumption and over drying were lower for harvesting on 1 September than on 15 August or 15 September. A harvest moisture content of 22% resulted in considerably higher costs for drying than for 19 or 16% moisture contents. Using an airflow greater than the required minimum rate resulted in higher energy consumption and over drying in most years. Drying performance was the same for three weather stations, Winnipeg, Brandon and Dauphin, which are representative of Manitoba's cereal growing area.

Pour aider les concepteurs et exploitants de systèmes, on a produit des courbes de probabilité relatives au séchage du blé avec de l'air quasi ambiant, à partir de données météorologiques enregistrées sur une période de 33 ans. Les dimensions du ventilateur, la consommation d'énergie et le surchauffage étaient inférieurs pour la récolte du 1^{er} septembre par rapport à celle du 15 août ou du 15 septembre. Un taux d'humidité de 22 % a occasionné des coûts beaucoup plus élevés pour le séchage de la récolte que les taux de 19 ou de 16 %. L'utilisation d'un flux d'air supérieur au minimum requis a entraîné une consommation d'énergie plus élevée et un surchauffage, la plupart des années. Les rendements du séchage étaient les mêmes pour trois stations météorologiques, Winnipeg, Brandon et Dauphin, qui sont représentatives de la zone de culture de céréales du Manitoba.

INTRODUCTION

Near-ambient grain drying occurs when a fan is used to force outside air through a grain bulk primarily to reduce the grain moisture content. The term, near-ambient, is applied because the temperature of the ventilating air is elevated as much as 6°C (Huminicki and Friesen 1983) above that of the ambient surroundings by compression from the fan and addition of heat from the fan motor. Near-ambient drying, unlike heated air drying, usually has lower initial capital investment, energy cost and heat damage to the dried grain (Otten et al. 1977).

Our computer model of drying grain with air at near-ambient conditions was developed by Metzger and Muir (1983) from the Thompson (1972) model and was further validated and modified by Sanderson et al. (1989). The model was then used to produce design data for Manitoba based on a 33-year data base of Manitoba weather (Friesen and Huminicki 1986, Table 3A). The minimum airflow rate required to dry wheat to 14.5% moisture content before November 15 without loss of quality in any of the 33 years was determined. For designers and operators to make more informed decisions further information was needed on the probabilities and variability of the simulated results. The aim of this investigation was to provide such information using the time to dry the top of the grain bulk to 14.5%, the final average moisture content of the grain bulk and the energy requirements of the drying system as dependent variables or comparison criteria.

METHOD

Field experiments are the most reliable and accurate means to determine the performance of a grain drying system using near-ambient air, but the expense in time and capital is prohibitive. By using a computer simulation program the combined effects of design variables and weather variability can be readily studied with minimal cost.

Comparisons were based on three criteria; time to dry, energy usage, and final average moisture content for the simulated bin. For each set of drying parameters, e.g. harvest date and initial moisture content, 33 separate computer simulations were carried out using weather data for the years 1953 to 1985. Probability curves were then developed for each set of drying parameters by sorting the results of each criterion in ascending order and plotting against an ordinate axis labelled 0 to 100% cumulative probability rather than 0 to 33 years.

The effects of harvest dates (August 15, September 1 and September 15) when drying wheat from an initial moisture content of 19% (wet mass basis) were simulated using the minimum airflows (15.0, 13.0 and 30.0 $L \cdot s^{-1} \cdot m^{-3}$) required to dry the top layer of the grain bulk to 14.5% before November 15 without quality loss in all 33 years at Winnipeg (Friesen and Huminicki 1986). Three moisture contents (16%, 19% and 22%) were compared for a harvest date of September 1 using the minimum required airflows of 10.0, 13.0 and 40.0 $L \cdot s^{-1} \cdot m^{-3}$ respectively. Six airflow rates (9.0, 13.0, 19.5, 26.0, 32.5, and 39.0 $L \cdot s^{-1} \cdot m^{-3}$) were compared for a September 1 harvest and moisture content of 19%. The last four airflow rates are 1.5, 2, 2.5 and 3 times the minimum required rate 13.0 $L \cdot s^{-1} \cdot m^{-3}$ (Friesen and Huminicki 1986). The effect of a rate (9.0 $L \cdot s^{-1} \cdot m^{-3}$) somewhat below the minimum required rate was also included. In addition to simulating drying in each of the 33 years with the six airflow rates, simulations were carried out using weather data for an "average year". The "average year" consisted of the ambient conditions averaged on an hourly basis for the 33 years of weather data. The results for the average year were compared with the results for the median years. For any given set of drying conditions and for each criterion, e.g. energy use, the value of the criterion for the median year is exceeded in one-half (16) of the 33 simulated years. The date of the median year varies among drying conditions and criteria. The median value of a criterion or simulated result provides a point of comparison for which 50% of all other simulated values are below and 50% are above.

Simulations using weather data from three stations representative of Manitoba cereal crop growing area were compared for a September 1 harvest and 19% initial moisture content using the same minimum airflow of 13 $L \cdot s^{-1} \cdot m^{-3}$. The three stations, Winnipeg, Brandon and Dauphin, are located in the three climatic zones covering Manitoba farming, Humid Prairie, Sub-Humid Prairie and Sub-Boreal (Putnam and Putnam 1970).

RESULTS

Harvest date

Wheat harvested on September 15 dried to below 14.5% moisture content in the fewest days, ranging from 11 to 40 (Fig. 1a) with a median of 17 (i.e. for one-half of the years the drying time was less than or equal to 17 days). For a September 1 harvest date drying times ranged from 24 to 70 days with a median of 35 days and for an August 15 harvest ranged from 17 to 45 days with a median of 25 days. The median calendar dates to complete drying for harvests on September 1 and 15 were similar, October 5 and 2 respectively. Minimum airflow rates for these two dates were limited by the design condition that the last layer (top layer) was to be dried to 14.5% before November 15 rather than by the spoilage criterion. The median dry date of September 9 for August 15 harvests was much earlier than the other two harvest dates. A higher airflow rate of 15 $L \cdot s^{-1} \cdot m^{-3}$ for the August 15 harvest date was required to prevent grain spoilage at the higher ambient air and grain temperatures in August.

Energy use for the September 15 harvest date was much higher than for the other two harvest dates due to the much higher power demand of the higher airflow required to complete drying by November 15 (Fig. 1b). Fraser and Muir (1981) also have shown that decreasing the drying time by increasing fan power and airflow rate results in increased energy consumption.

Final moisture contents averaged over the bin depth at the end of drying varied considerably during the 33 years of simulations (Fig. 1c). At lower cumulative probabilities, 25% and below, the August 15 harvest date had lower moisture contents than either of the September harvest dates. The lower moisture contents for an August 15 harvest occur mainly due to the increased drying potential of the usually warm summer ambient air during the earlier drying period. Because of the required higher airflow to complete drying by 15 November, wheat harvested on September 15 frequently dried to a lower moisture content than wheat harvested on September 1.

Initial moisture content

Wheat harvested at 22% moisture content had to be dried faster than wheat at 16 and 19% because high moisture content wheat can spoil quickly (Fig. 2a). High power demand and energy consumption (Fig. 2b) were required to remove the large quantity of moisture from the 22% wheat before it underwent excessive spoilage. Similarly the amount of energy required to dry 16% wheat was half the energy required to dry 19% wheat. Final average moisture contents were lowest for the highest initial moisture content of 22% (Fig. 2c). The small difference in final moisture content between simulations for the 16 and 19% moisture content wheat can be directly attributed to the similarity in the number of days required for the grain to dry.

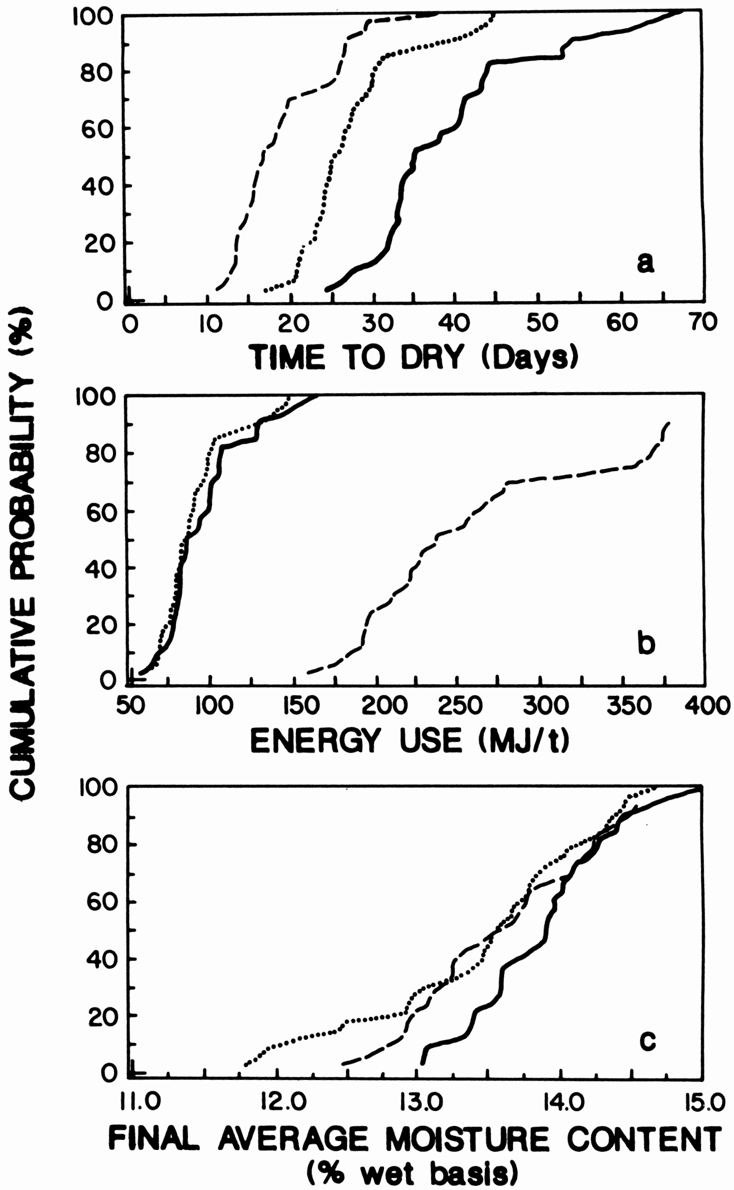

Fig. 1. Cumulative probabilities based on 33 years of weather data at Winnipeg, Manitoba, for wheat harvested at an initial moisture content of 19% wet mass basis on August 15 (• • • • • •), September 1 (———) and 15 (— — —) and dried with near-ambient air at required minimum airflows of 15, 13 and 30 $L \cdot s^{-1} \cdot m^{-3}$ respectively.

Airflow rate

Increasing the rate of airflow above the minimum (13 $L \cdot s^{-1} \cdot m^{-3}$) required in the worst year reduced the time to dry and increased the energy consumption in every year (Fig. 3a and 3b). For about 25% of the years decreasing the airflow to

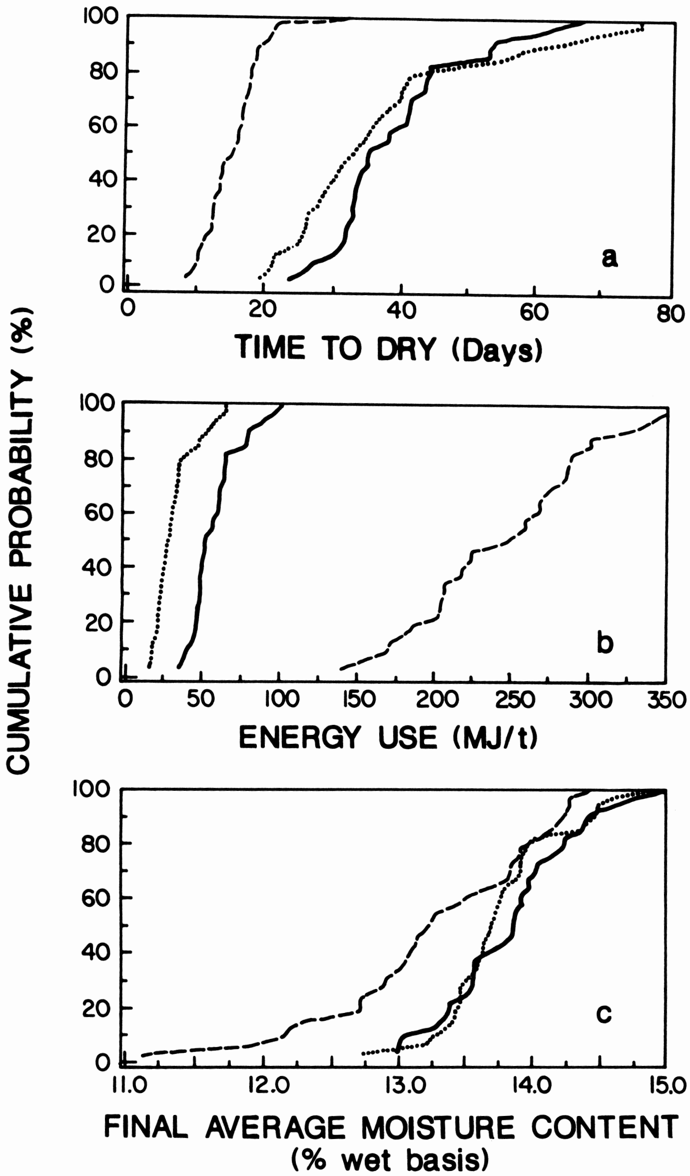

Fig. 2. Cumulative probabilities based on 33 years of weather data at Winnipeg, Manitoba, for wheat harvested on September 1 at initial moisture contents of 16 (• • • • • •), 19 (——) and 22% (— — —) wet mass basis and dried with near-ambient air at required minimum airflows of 10, 13 and 40 L•s^{-1}•m^{-3} respectively.

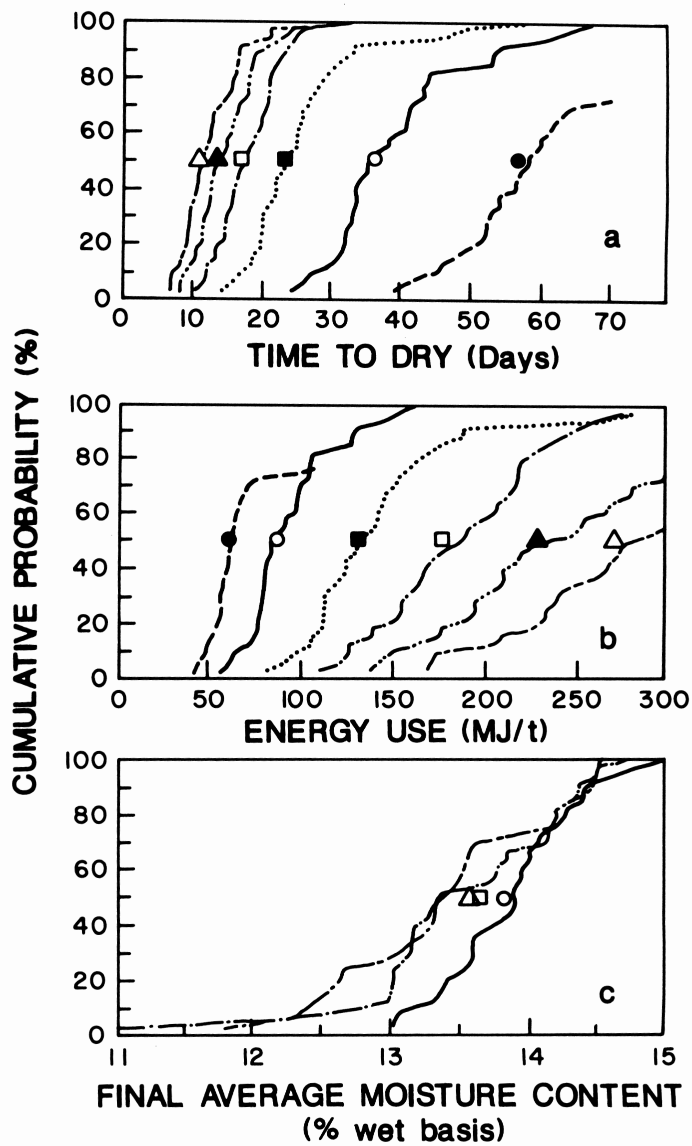

Fig. 3. Cumulative probabilities based on 33 years of weather data at Winnipeg, Manitoba, for wheat harvested on Setpember 1 at 19% initial moisture content wet mass basis and dried with near-ambient air at airflows above and below the required minimum rate of 13 L•s^{-1}•m^{-3}. The lines indicate cumulative probabilties. The symbols plotted at 50% cumulative probability (i.e. at the median year level) indicate the simulated results using the "average year" weather data that consists of the ambient air conditions for 33 years averaged on an hourly basis. The airflow rates in L•s^{-1}•m^{-3} were 9 — — — (●), 13 ——— (O), 19.5 • • • • • • (■), 26 — • — (□), 32.5 — •• — (▲) and 39 — - — (Δ).

9 L•s^{-1}•m^{-3} resulted in incomplete drying by 15 November and energy consumption greater than that for the minimum airflow of 13 L•s^{-1}•m^{-3}. Final average moisture contents (Fig. 3c) varied but the higher airflows, 39 and 26 L•s^{-1}•m^{-3}, tended to have lower final average moisture contents. This lower moisture content for higher airflows can be attributed to completion of drying earlier in the season when the potential for drying is higher.

Average year

Simulations using averaged weather data had close correlation to the median year for the number of days to dry and energy used (Fig. 3a and 3b). The differences in final average moisture contents were larger (Fig. 3c) than those for days to dry or energy use, but still indicate the same effects of airflow as those for the 33-year simulations. The number of days to dry

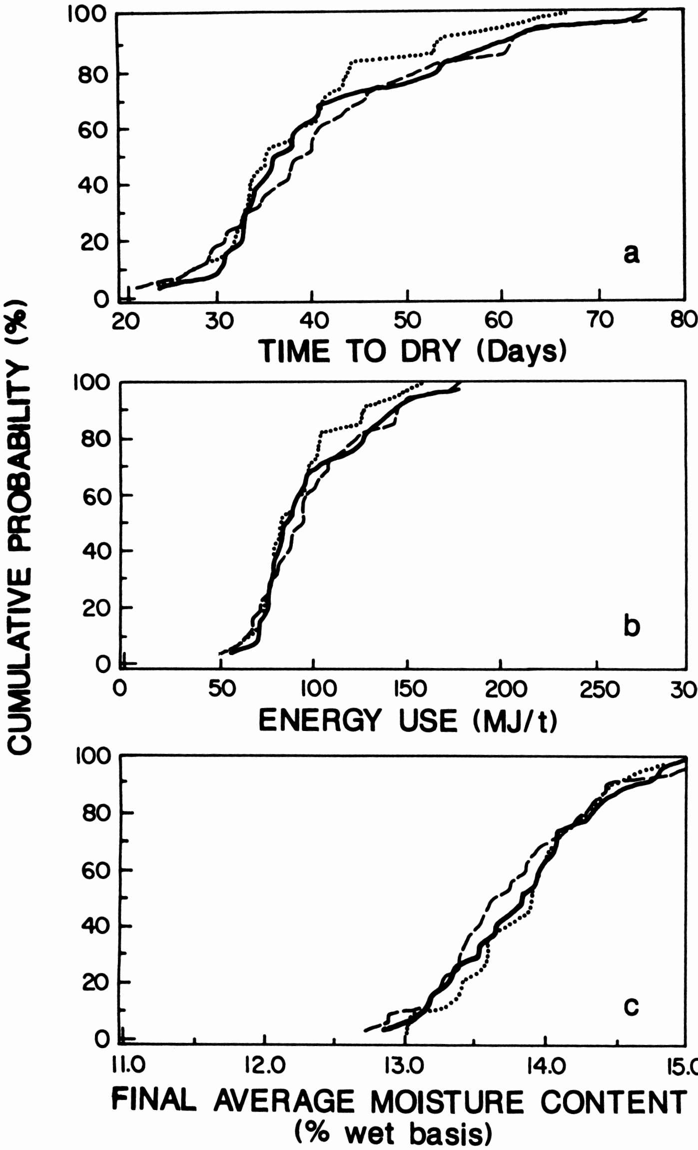

Fig. 4. Cumulative probabilities based on 33 years of weather data for wheat harvested on September 1 at 19% moisture content and dried with near-ambient air at a required minimum airflow of 13 L•s^{-1}•m^{-3} at Brandon (———), Dauphin (— — —) and Winnipeg (• • • • • •), Manitoba.

and the energy usage were directly affected by the overall drying season, whereas the final moisture contents were influenced more by the year to year variation in the weather during the final portion of the drying season.

Climatic zone

The differences in drying among three Manitoba locations were negligible compared with the year to year variations (Fig. 4). Drying occurred slightly faster and resulted in higher final moisture contents under the relatively warm Humid Prairie climate of Winnipeg compared with the Sub-Humid Prairie climate of Brandon and the Sub-Boreal climate of Dauphin.

DISCUSSION AND CONCLUSIONS

Results presented in this paper add to the information in the tables of minimum airflow rate recommendations that are available to designers and operators (Friesen and Huminicki 1986). Inferences may now be drawn about the performance of a near-ambient drying system and expected variabilities in time to dry, energy use and final moisture content. Managers of grain drying systems can use the time to dry information in planning when the grain can be used or sold and when a drying bin may be available to dry a second batch. Energy use and final moisture content can be used to indicate or calculate comparative drying costs. Wheat is marketed in Canada on a wet mass basis at a constant price per unit mass for any moisture content at or below 14.5%. Thus, the monetary value of an initial quantity of wheat decreases because of over drying according to the mass of water removed below a moisture content of 14.5%.

The time to dry tends to be much longer in 5 to 20% of the years compared with the other years (Figs. 1 to 3). Thus a grain storage manager could be willing to reduce fan size and cost with the expectation that in some years drying may be incomplete or some spoilage may occur. An alternative management strategy that can be considered is using a bin to dry two or more separate bulks each year. For example, wheat at 19% harvested on August 15 could be dried within 30 days in 85% of the simulated years (Fig. 1). The bin could then be emptied before 15 September and partially refilled with freshly harvested wheat so that airflow was doubled to 30 L•s^{-1}•m^{-3}.

The effect of airflow rate on probabilities of drying within a certain time can vary considerably. For the conditions defined in Fig. 3 increasing airflow rate from 13 to 19.5 L•s^{-1}•m^{-3} increases the probability of drying within 30 days from 10% to 80% but only increases the probability from 60% to 90% for drying within 40 days. A grain storage manager can compare the performance of his system in the present year against the simulated probabilities to determine whether the present year is near an extreme year or nearer a median year.

The cumulative probabilities for any value of the three criteria are the same for the three Manitoba locations. The simulated data, however, show that for some years the results can vary widely among the locations.

For the conditions and design limits used in the simulations the September 1 harvest date resulted in the lowest costs of fan size, energy consumption and overdrying (Fig. 1). The earlier harvest date of August 15 had similar low energy costs with a slightly larger fan but cost of overdrying was greater than for September 1. A major advantage for an August 15 harvest date was that for the median year drying was completed a month earlier than when harvesting was delayed by one-half month.

Harvesting at 22% moisture content rather than 16 or 19% required a greatly reduced drying time to prevent excessive deterioration of the undried wheat (Fig. 2). This was achieved by large increases in airflow rate, energy use and overdrying.

By increasing the airflow above the minimum required airflow, drying times were reduced but both energy use and fan size were increased (Fig. 3). Also the final average moisture contents decreased slightly, overdrying the wheat below 14.5% and increasing the related cost of reduced saleable mass. A simulated drying system using an airflow below the required minimum performed adequately for 75% of the years giving lower energy usage and less overdrying of the wheat, but for 25% of the years the drying times became excessive, energy usage increased and drying was not completed by November 15.

Predicted results for the average year were close to those for the median years of the 33 year data base. Even when the airflow rate was changed by a factor of three, which in turn changed the exact year that was the median year, the correlations of days to dry and energy usage were satisfactory. Final moisture contents were not as closely correlated but a trend to lower final moisture contents for higher airflow rates was shown.

The simulations indicated that the performance of a near-ambient drying system was similar at three locations in the three climatic zones of the Manitoba farming region. Brandon and Dauphin are near the boundaries of their zones and may not be representative of their drier and colder climatic zones.

ACKNOWLEDGEMENTS

We thank the Natural Sciences and Engineering Research Council of Canada (NSERC) for a Strategic grant.

REFERENCES

FRIESEN, O.H. and D.N. HUMINICKI. 1986. Grain aeration and unheated air drying. Agdex Publ. 732-1. Manitoba Agriculture, Winnipeg, MB.

FRASER, B.M. and W.E. MUIR. 1981. Airflow requirements predicted for drying grain with ambient and solar-heated air in Canada. Trans. ASAE 24:208-210.

HUMINICKI, D.N. and O.H. FRIESEN. 1983. Fan test results. Publ. MG-9025, Manitoba Agriculture, Winnipeg, MB.

METZGER, J.F. and W.E. MUIR. 1983. Computer model of two-dimensional conduction and forced convection in stored grain. Can. Agric. Eng. 25:119-125.

OTTEN, L., A.G. MEIERING, R. BROWN and T. DAYNARD. 1977. Ventilation and low temperature drying of corn. Paper No. 77-107. Can. Soc. Agric. Eng., Ottawa, ON.

PUTNAM, D.F. and R.G. PUTNAM. 1970. Canada: A regional analysis. J.M. Dent and Sons (Canada), Toronto, ON. p. 390.

SANDERSON, D.B., W.E. MUIR, R.N. SINHA, D. TUMA and C.I. KITSON. 1989. Evaluation of a model of drying and deterioration of stored wheat at near-ambient conditions. J. Agric. Eng. Res. 42: 219-233.

THOMPSON, T.L. 1972. Temporary storage of high-moisture shelled corn using continuous aeration. Trans. ASAE. 19:318-321,325.