Environmental Factors Affecting Soybean Growth in Manitoba

by

Gary Falk

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Department of Plant Science

Winnipeg, Manitoba, 1981

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ABSTRACT

A model to predict daily development of soybeans (Glycine max.) based on environmental factors was developed for Manitoba. By accurately modelling daily development, a date of maturity was predicted.

The biometeorological time scale formula (BMTF) (Robertson, 1968) predicts daily development based on maximum and minimum temperatures, and daylength. The time from emergence to physiological maturity of soybeans was divided into three phases in which environmental factors were thought to exert a uniform influence. An iterative regression analysis technique by Robertson (1968) was used to relate development throughout the observed period of a phase at all nine stations years to actual temperature and daylength values on these days. The resulting regression coefficients were then used in the BMTF.

The BMTF was able to predict within 2-3 days, the date of maturity using an observed emergence date for the test data. A predicted date of emergence from planting was arrived at by performing regression analysis of daily development (1/days to emergence) on average soil temperature at 20 cm. Predicted emergence dates resulted which were usually within 3 days of the observed date. The model predicting emergence date from soil temperature was incorporated into the BMTF to get a predicted date of maturity from an observed planting date. Predicted maturity date was usually within 4-5 days of the observed maturity date.

A certain degree of bias towards earliness was introduced into the model as a result of water stress on most of the sites throughout the period of the experiment. Further testing to correct this bias is needed. As well, the number of station years of test data must be increased and then the model must be tested on independent data.

ACKNOWLEDGEMENTS

I wish to thank Dr. C.F. Shaykewich under whose supervision this research program was undertaken. His generous assistance and guidance throughout this period have been invaluable.

As well, a word of thanks is due to Dr. E.H. Stobbe, Mr. G.M. Young, and Mr. A. Reimer for serving on the examining committee.

I would also like to thank Diane, Gord, and the Agriculture Canada crews at Morden and Brandon for their assistance in establishing the sites.

A special thank you is expressed to my wife, Theresa, for her love, support, and assistance.

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Chapter I

INTRODUCTION

The possibility of producing soybeans commercially in Manitoba has been considered recently. Because the growing period for soybeans tends to be considerably longer than cereal crops, the question of whether soybeans can attain maturity prior to the first autumn frost becomes important.

The goal of this research program was to assess the effect of environmental parameters on growth of soybeans. Field studies throughout Manitoba were conducted to measure soil temperature, soil moisture, air temperature, and daylength as well as to monitor phenological development of the soybeans throughout the growing season. It was postulated that a model (the biometeorological time scale formula (Roberston, 1968)) could be developed which would predict daily development from maximum and minimum temperature and daylength.

When an adequate prediction model for the data involved in the development of the model had been created it was postulated that this model could be further tested on independent data. If this model was still accurate enough (as arbitrarily defined), it would then be applied to historical climatic data and areas could be mapped as to their suitability for soybean production.

Chapter II

LITERATURE REVIEW

2.1 TEMPERATURE EFFECTS ON SOYBEAN GROWTH AND DEVELOPMENT

2.1.1 GERMINATION AND SEEDLING DEVELOPMENT

The rate of germination and seedling emergence of soybeans is dependent upon soil temperature (Hopper *et al.*, 1979; Hatfield and Egli, 1974). An increase in temperature up to an optimum resulted in an increase in the percent of germination as well as the rate of germination (Wilson, 1928). Rate of germination as measured by the length of time for the seedling to reach a length of 5 mm, increased over the range of 10C (the minimum germination temperature) to 30C (the optimum germination temperature) (Wilson, 1928). The percent of seeds germinating also increased throughout this range, however the maximum germinating was reached at 25C and remained constant up to 30C. Wigham and Minor (1979) reported slightly lower minimum germination temperatures than those of Wilson (1928). They reported a minimum germination of 5C, an optimum of 30C, and a maximum of 40C. Their optimum and maximum temperatures agreed with the results of Hatfield and Egli (1974) who used hypocotyl elongation as an indicator of germination and emergence.

Gilman *et al.* (1973) studied the effect of temperature on hypocotyl elongation in the range of 20 to 30C using different soybean cultivars than Hatfield and Egli (1974). They found an inhibition of hypocotyl elongation when seeds were exposed to a temperature of 25C. The longer the exposure of germinating seeds to this temperature the greater was the inhibition of hypocotyl elongation. The severity of inhibition varied from cultivar to cultivar. This inhibition of hypocotyl elongation was offered as one of the reasons for spotty and inconsistent germination and emergence patterns under field conditions.

Low temperatures (5-15C) impair germination and cause seedling damage in soybeans (Obendorf and Hobbs, 1970; Knypl and Janas, 1979). Seeds with low moisture content (6%) were more sensitive to cold temperatures during imbibition than high moisture (16%) seeds (Obendorf and Hobbs, 1970). Cold temperature injury was expressed most noticeably as a reduction in seedling survival, next as a reduction of dry matter accumulation per seedling and least as a reduction in plant height two weeks after cold imbibition. Because of the effect of moisture content on cold temperatures during imbibition, Knypl and Janas (1979) proposed a pretreatment of seeds under water saturated conditions prior to germinating in cold temperatures. Hypocotyl and root growth were increased significantly and chilling injury was severely decreased following this treatment. As well as enhancing germination and accelerating emergence from the soil, subsequent shoot and primary leaf growth was also enhanced. Cold chilling injury was probably due to a physical disruption of a metabolic system (Obendorf and Hobbs, 1970) where low temperature interfered with the cell membrane reorganization during imbibition (Knypl and Janas, 1979). In more northerly latitudes cold temperatures could play a significant role in hindering the establishment of good stands of soybeans.

2.1.2 VEGETATIVE GROWTH

The average rate of development (defined as the reciprocal of the number of night hours between phenological stages) of soybeans was highly correlated to temperature in the pre-flowering stage (Brown and Chapman, 1960). An earlier study by Brown (1960) determined that this relationship was curvilinear. The threshold (minimum) temperature occurred near 10C and the optimum near 30C. The time from planting to cotyledon, planting to unifoliate, unifoliate to trifoliate, and between trifoliates decreased as temperatures were increased over the range of 13 to 30C. No advantage in rate of growth or time between stages was observed above 30C (Hesketh *et al.*, 1973). Growth of soybeans ceased at 40C (Wigham and Minor, 1978).

Temperature affects the time between vegetative stages by affecting the response of different growth parameters. Leaf area (LA) increase and dry matter (DM) accumulation as measurements of growth rate were markedly affected by temperature (Hofstra, 1973). The greatest effect of temperature on increase in LA and DM occurred at early stages of growth. Maximum response occurred at 27C. Rate of leaf appearance and stem elongation increased as temperatures increased (Hofstra, 1973).

Low temperatures resulted in slower rates of growth and longer periods of time between vegetative stages (Hofstra, 1973). As well, Hofstra (1973) observed that a higher percentage of assimilates went to axillary growth at lower temperatures suggesting that an excess of assimilates was present for new leaf growth, particularly on the main stem with this treatment. This redistribution of assimilates could result in morphological changes in the plant.

Response to temperature during vegetative growth was found to be variety dependent (Major et al., 1975a). Early maturing varieties were more dependent on temperature than were later maturing varieties. Reasons for this will be discussed in the section on photoperiod effects.

2.1.3 REPRODUCTIVE GROWTH

It was recognized in the late 1950's and early 1960's that the relationship between crop development and temperature was much closer for the pre-flowering period than for the post-flowering period (Brown, 1960; Hesketh et al., 1973). The time period between different reproductive stages, as well as the length of the entire reproductive phase was fairly invariant of temperatures over the range of 20 to 30C.

While temperatures in the 20 to 30C range may not affect the length of the reproductive period, the number of flowers and pods produced and shed is affected. It was observed that day and night temperatures seemed to contribute to the effect separately (van Shaik and Probst, 1958). Increasing the temperature over the range of 20 to 30C seemed to enhance flower production. However, when night temperatures were lower than day temperatures the number of flowers produced was reduced (van Shaik and Probst, 1958). Pod production was generally unaffected by lower night temperatures. The percent of flowers and pods shed increased as the day temperature was increased from 20 to 30C regardless of night temperature (van Shaik and Probst, 1958).

Cool daily temperatures such as those temperatures encountered in fall (Major et al., 1975b) or below 21C (van Shaik and Probst, 1958) delayed development following flowering when daylength was held constant.

Kao (1980) also noted that low temperatures (20C for day and 15C for night) at the pod-fill stage significantly retarded leaf senescence of podded soybean plants. This could result from a decrease in the metabolism of the primary leaves. The retardation of leaf senescence would likely result in a delay in maturity of the crop.

An extension of the reproductive period may be desirable however. Low temperatures which tend to delay development, even in the reproductive phase can have a desirable effect on seed size and yield by extending the length of the filling period (Egli and Wardlaw, 1980; Egli et al., 1978). A balance is therefore sought which maximizes the length of the filling period without jeopardizing the plant by delaying maturity.

2.2 LIGHT EFFECTS ON SOYBEAN GROWTH AND DEVELOPMENT

Light affects growth and development of plants in two ways. First, light is an energy source used to assimilate carbon. Secondly, photoperiodic responses that affect development of plants, particularly floral initiation, are known to occur.

2.2.1 LIGHT AS AN ENERGY SOURCE

Light is an essential energy source for photosynthesis. The amount of light energy or intensity of light then becomes important provided CO_2 is not limiting. Plants grown in the greenhouse showed increased apparent photosynthetic rates up to 23,000 lux, which is about 20% of full sunlight (Bohning and Burnside, 1956). Beuerlein and Pendleton (1971) grew soybeans under field conditions and found the upper canopy leaves became light saturated with respect to photosynthetic rates at light intensities of 10,000 to 11,000 footcandles (107,680 to 118,400 lux), i.e. very close to full sunlight. Plants spaced wide apart showed an increase in photosynthetic rates up to 15,000 footcandles which is beyond full sunlight. The plants had up to 5 times more light than normal and showed increases in number of nodes, branches, pods, seeds, pods per node, seeds per node and higher oil content. Seed size and protein content were decreased, however. These responses were achieved using CO_2 concentrations of 360 ppm. Current levels of CO_2 in the atmosphere are about 335 ppm.

In the lower portion of the canopy, light is often limiting. Johnston *et al*. (1969) showed increases in yield of bottom and middle plant parts of 20 and 30% respectively when additional light was supplied. Bottom and middle plant parts also fixed more CO_2 (258% and 50% more respectively) when additional light was provided.

2.2.2 PHOTOPERIODIC RESPONSES

2.2.2.1 FLOWERING

Garner and Allard (1920) first showed that soybean development, particularly the time from emergence to flowering, was influenced by daylength. At this time it was observed that short photoperiods enhanced the flowering process in soybeans. It is now generally recognized that night length rather than daylength induces the photoperiodic response.

There are plants with an absolute requirement for short-day induction and others whose flowering is only hastened by shortdays (Street and Opik, 1976). The literature was somewhat unclear as to which, or to what degree, soybeans belong in either catagory. Brown (1960) concluded from experimentation that more days are needed to reach flowering at longer photoperiods. van Shaik and Probst (1958) drew the same conclusion for one variety (Clark) but stated the effect was less consistent in another variety (Midwest). Hicks (1977) however, stated that " in the field, the soybean will flower only when the night length exceeds a critical length."

2.2.2.2 OTHER RESPONSES

Daylength affects more than just flowering in soybeans. van Shaik and Probst (1958) observed that longer photoperiods, along with increases in temperature resulted in faster plant growth and greater final plant heights. They also found that percent flower and pod shedding was increased by longer photoperiods. Shanmugasundarum (1979) found that a long photoperiod (16 hrs.) delayed flowering and resulted in a delay in the time to maturity, increased plant height and node number at flowering and maturity. It also resulted in longer flowering duration, more flowers and pods per plant and higher yield. They suggested that these increases were the result of greater vegetative development under long photoperiod.

Rate and duration of the pod-fill stage is also under photoperiodic control (Thomas and Raper, 1976; Patterson _et al_., 1977). Reports in the literature appeared somewhat inconsistent as to how pod-fill was affected by photoperiod. Johnson _et al_. (1960) found that shortening the photoperiod after floral initiation reduced the interval between seed set and maturity. Patterson _et al_. (1977) altered the daylength during the pod-fill period and found that increasing the daylength increased the rate of pod-fill and decreased the length of the pod-fill stage.

The average rate of fill of the long daylength treatment was observed to be 1.3 times that of the short day treatment. This ratio closely corresponded to a ratio of 1.32 for the total daily amounts of photosynthetically active radiation received in the respective photoperiod treatments after photo-induction was complete. Thomas and Raper (1976) observed that increasing the number of consecutive photo-inductive short days increased the weight per pod. They presumed this increase in pod weight was a result of an increase in the rate of pod fill. While the picture remains somewhat unclear as to the photoperiodic effect during this period, the implications may be quite significant.

Thomas and Raper (1976) stated that in the field situation the daylength was constantly decreasing following the summer solstice. If their hypothesis is correct, the rate of pod-fill would be expected to accelerate as reproductive development progresses. This would result in an increased demand for nutrients especially nitrogen. Since these demands could not be met by the plant, leaves would begin to senesce resulting in premature cessation of the pod-fill period. If the photo-induction and rate of pod-fill photoperiodic responses could be uncoupled a longer photo-inductive daylength might be coupled with a shorter critical daylength to affect pod-fill. The result might be an extension of the pod-fill period due to a decrease in the rate of fill and a possible increase in yield.

2.2.2.3 VARIETAL DIFFERENCES IN RESPONSE TO DAYLENGTH

A very large number of soybean varieties have been tested to observe their response to photoperiod. Results indicate that soybean varieties differ in their responses to photoperiod (Johnson *et al.*, 1960). van

Shaik and Probst (1958) noted that the two soybean varieties Clark and Midwest responded differently to photoperiodic variations. Since these early observations were made, varietal sensitivity to photoperiod has received a good deal of attention.

Polson (1972) tested 79 different soybean varieties for flowering response at different photoperiods. Results indicated that all strains tested flowered within 35 days at a 12 hour photoperiod. As photoperiod increased, however, some varieties increased the number of days to flowering. It was observed that early maturing varieties were less sensitive to photoperiods than later maturing varieties. Johnston *et al.* (1960) had made a similar observation. Polson (1972) noted that these early maturing varieties are generally grown in more northern latitudes where the daylength is longer and the growing season shorter, indicating that early maturity and response to daylength may be interrelated.

In the mid 1950's several different researchers (Yoshida, 1952; and Pohjakallio and Antila, 1957) presented evidence that some early maturing soybean varities were insensitive to photoperiod. Recent studies have supported this statement. Polson (1972) tested numerous early maturing varieties (from maturity groups 00 (earliest), and 0) for daylength responses or lack thereof. Some strains were unaffected in time to flowering even under photoperiods of 22 hours leading the author to conclude that induction to flowering was not influenced by daylength in these strains of soybeans. It should be noted, however, that both photoperiod sensitive and insensitive strains of soybeans were observed in both 00 and 0 maturity groups. This led the author to conclude that while day-neutrality was generally associated with early maturity, it was partially an independent response. Criswell and Hume (1972) observed that in some strains where flowering was delayed by a lengthened photoperiod, the interval from flowering to pod formation was also delayed. Shanmugasundarum (1979) used 39 varieties which Criswell and Hume (1972) had found to be insensitive to daylength and 1 photo-sensitive variety. He investigated the responses of 12 different characters under 10 and 16 hour photoperiods. Included in the characters investigated were days to flower, flower and pod numbers, plant height, flower duration, days to maturity, grain yield, and seed weight. Seventeen varieties were insensitive to all 12 characters while plant height, nodes at maturity, days to maturity and yield were influenced most in the other 23 varieties.

Several varieties grown in Manitoba have been tested for photoperiod sensitivity. Portage (Criswell and Hume, 1972) and Maple Presto (Major, 1980) were both found to be insensitive to daylength with respect to flowering.

Daylength, thus plays a vital role in the growth and development of most soybean varieties. Delays in flowering may have benificial effects in that more dry matter accumulation can occur, however it may also have adverse effects in delaying maturity of the crop.

2.3 TEMPERATURE - PHOTOPERIOD INTERACTIONS

While both temperature and photoperiod make a vital contribution to soybean growth and development by themselves, it is evident that they operate in conjunction with each other as well as with other environmental factors. Significant delays in floral initiation upon receipt of the inductive short photoperiod under low temperatures have been observed. Parker and Borthwick (1943) concluded that this interaction between photoperiod and temperature was a result of temperature influencing photoperiodic reactions in the leaf blade. Photoperiodic responses controlling the rate of seed fill were also observed to be temperature dependent (Tomas and Raper 1976). van Shaik and Probst (1958) observed that floral initiation was delayed by either decreasing the temperature or increasing the photoperiod. In the latter study it appears that an additive effect rather than an interacting effect existed between temperature and photoperiod. Lowering the temperature at an optimum photoperiod produced the same effect as increasing the photoperiod while maintaining the optimum temperature.

2.4 MOISTURE EFFECTS ON SOYBEAN GROWTH AND DEVELOPMENT

2.4.1 GERMINATION AND SEEDLING DEVELOPMENT

An adequate supply of moisture is essential for germination of soybeans. Soil water potentials (SWP) of greater than -6.6 bars were necessary to ensure good germination (Hicks, 1978). This was considerably higher than for other crops. Hunter and Erickson (1952) found that the soil water potential for emergence had to be higher than for germination. The optimum soil water potential for emergence was from -0.1 to -0.7 bars in a clay soil and -0.4 to -0.6 bars for a silt - loam soil (Heatherly and Russell, 1979).

Small seeds were found to germinate more rapidly than larger seeds at similar water potentials (Edwards and Hartwig, 1971). They suggested that it may be benifial to use uniform small seeds when soil water potentials are low to facilitate more rapid and even germination.

2.4.2 GROWTH PARAMETERS

Growth and development of soybeans is greatly influenced by the availability of moisture. Read *et al*. (1972) found that the leaf area ratio(1) (LAR) decreased when soybeans were stressed. Lower leat area ratios would decrease transpiration losses. As well, photosynthetic efficiency increased as was evidenced by an increase in the net assimilation rate(2) (NAR). The net result was fewer leaves that were photosynthetically more efficient. Relative growth rate(3) (RGR) of the root increased and RGR of the shoot decreased when plants were stressed. This response resulted from an increase in the root to shoot ratio. Such a redistribution of assimilates from the shoot to the root would decrease water loss and increase water uptake (Read *et al*., 1972). As well as decreased LAR, increased cuticle thickness in response to moisture stress (Ciha *et al*., 1975) will serve to further reduce transpiration losses.

Studies such as those mentioned above serve to illustrate that soybeans possess the physiological capacity to grow under moisture stress conditions. Heatherly *et al*. (1977) measured the actual soil water potential at which growth was affected. At soil water potentials of less than -4 bars, leaf enlargement was reduced by 75% and had ceased altogether at -12 bars. Therefore it appears that while soybeans can withstand stress conditions, high soil water contents are necessary to max-

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(1) LAR = the ratio of assimilatory material per unit area of plant material.

(2) NAR = the increase of plant material per unit of leaf area per unit time.

(3) RGR = the increase of plant material per unit of material present per unit time.

imize growth during the vegetative stage.

2.4.3 SEED YIELDS

Insufficient water throughout the growing season is frequently the major barrier to high soybean yields. The extent of the yield reduction depends upon the time and duration of the stress period. Doss *et al*. (1974) concluded that yield reductions were greatest when plants were stressed throughout the entire growing season. The most critical time for the plant to be stressed was during the pod-fill stage. Using historical data, Runge and Odell (1960) found that an additional 2.5 cm of precipitation above the average for an eight day period during pod-fill resulted in a yield increase of 134 kg/ha. Others have found increases of 240-403 kg/ha with irrigation during the seed development period (Doss *et al*., 1974).

Mederski and Jeffers (1973) tested varieties from different maturity groups for their yield response to moisture stress. Lower yielding varieties within a given maturity group under adequate moisture conditions tended to be less affected by moisture stress than higher yielding varieties within that same group. No trend was established however, between maturity groups as a whole. It was concluded that responses were dependent on the variety rather than on the maturity group.

2.4.4 THE LENGTH OF GROWTH STAGES

While temperature and daylength appear to be the major factors affecting the length of stages of development, moisture is also seen to affect their length. Robins and Domingo (1956), working with a variety of dry beans (Phaseolus vulgaris), found that plant development was retarded by moisture stress before blooming and hastened during blooming and maturation. A similar effect was observed by Brown and Chapman (1960) in soybeans. The reproductive period was shortened due to cessation of growth as a result of moisture stress. This phenomenon deserves a good deal of attention when attempting to model development especially in the reproductive phase of growth (Brown and Chapman, 1960).

2.5 CROP GROWTH MODELS

Numerous crop growth models have been developed attempting to relate development to temperature. Brown (1960) developed the concept of soybean development units (SDU´s). This model relates the average daily temperature to development in a curvilinear manner. There will then be a minimum, maximum, and optimum temperature at which development will occur. Brown (1960) and Major *et al*. (1975a) concluded that this model and other thermal unit models were fairly effective in predicting the time to flowering but were less effective for predicting the time from flowering to maturity. They suggested that other environmental factors, namely photoperiod and soil moisture, were influencing the reproductive phase. Major *et al*. (1975b) used the iterative regression analysis model developed by Robertson (1968). This model considered the effects of daylength and maximum and minimum temperatures on time to maturity and is described in Appendix A. It was found to be a better predictor of development than growing degree days because it accounted for daily changes of both daylength and temperatures.

Some research has been conducted to include solar radiation summations in crop growth models. It is argued that solar radiation summations are directly equivalent to amounts of thermal energy while temperature summations are an indirect result and thus more accuracy can be achieved by using models that relate growth to solar radiation summations (Sierra, 1977). No indication was given as to what wavelengths were included in the summations or what instruments were used to measure solar radiation. Solar radiation summations are generally obtained by measuring the amount of solar energy in the range of .3 to 3.0 microns with a pyroheliometer. This data is not available from most climatical stations. Therefore, because of the high correlation of temperature to solar radiation summations, temperature summation methods are customarily used with quite good results.

Chapter III

METHODS AND MATERIALS

The intent of the study was to investigate the effect of several climatic parameters on soybean growth in Manitoba. Emphasis was placed on the development of a prediction model using the biometeorological time scale formula (BMTF) (Robertson, 1968) to predict maturity based on temperature and photoperiod. The effect of soil temperature and soil moisture were also given some consideration. To accomplish these objectives, sites were selected throughout Manitoba to include as wide a variety of climatic conditions as possible. The study was conducted over a period of two years using three varieties of soybeans currently under consideration in Manitoba. They are Portage and McCall, two varieties that mature in about 110-120 days and Maple Presto, an earlier maturing variety (100-105 days) developed in Ottawa for the more northerly regions of soybean adaptation.

3.1 SITE DESCRIPTION

Because of the limitations of time and manpower, only five sites were chosen. Three of the five sites were established in cooperation with the Manitoba Crop Zonation Trials at Winnipeg, Waskada, and Dauphin. In 1979 duplicate soybean experiments were established adjacent to the soybeans grown for the Zonation Trials. In 1980 the Zonation Trials themselves were monitored. The two other sites were established at the Agriculture Canada research stations in Morden and Brandon by station personnel. Because of the number of different people involved in the establishment of the sites, there exists a good deal of variability in the size and design of the experiments. A description of the individual sites, plot size, and experimental design is given in Table 1. The soil type, fertilizer and herbicide application, seeding rates, and seeding equipment are given in Table 2. An effort was made to optimize soil fertility conditions and to create a weed free environment so that these factors would not differentially influence growth from station to station.

A total of nine station-years of data were collected. In 1980 the original intention was to establish two seeding dates at Winnipeg, Waskada, and Dauphin. However, an extremely dry spring and other "unusual circumstances" resulted in the loss of the two experiments at Winnipeg as well as two experiments at Waskada. The end result was that only four station years of data were collected in 1980 (one station year at Morden and Brandon and two station years at Dauphin) instead of eight as had been hoped.

TABLE 1

Description of Experimental Sites and Plots

Station	Location	Plot size	Experimental design
Winnipeg 1979	River lot 123 Parish of St. Norbert	1.2m x 5m 4 rows 30cm row spacing	completely randomized 3 treatments 4 replicates
Morden 1979	NE4-3-5W	2.4m x 5m 8 rows 30cm row spacing	randomized complete block; 3 treatments 4 replicates
1980	same as 1979	1.2m x 5m 4 rows 30cm row spacing	same as 1979
Waskada 1979	SE4-2-29W	1.2m x 5m 4 rows 30cm row spacing	randomized complete block; 3 treatments 4 replicates
Brandon 1979	SE28-10-19W	3m x 5m 10 rows 30cm row spacing	no randomization 3 treatments 4 replicates
1980	NE20-10-19W	same as 1979	no randomization 3 treatments 3 replicates
Dauphin 1979	SE36-24-19W	1.2m x 5m 4 rows 30cm row spacing	randomized complete block; 3 treatments 4 replicates
1st seeding date 1980	NW23-24-19W	same as 1979	randomized complete block; 5 treatments# 3 replicates
2nd seeding date 1980	same as 1st seeding date	same as 1979	randomized complete block; 3 treatments 4 replicates

Two additional varieties were included in 1980 Zonation Trials.

TABLE 2

Soil type, fertilizer and herbicide application, seeding rates and seeding equipment at experimental sites.

Station	Soil type	Fertilizer kg/ha	Herbicide	Plant[#] density plts/m^2	Seeding equipment
Winnipeg 1979	Riverdale Silty clay	none applied	Treflan 1.1 kg/ha	P 35 MC 47 MP 40	4 row plot seeder
Morden 1979	Morden fine loam-clay	none applied	Treflan 1.1 kg/ha	P 25 MC 29 MP 27	8 row conventional drill
1980	same as 1979	none applied	Treflan 1.1 kg/ha	P 70 MC 72 MP 60	4 row plot seeder
Waskada 1979	Waskada clay-loam	194 kg/ha 16-20-0	Treflan 1.1 kg/ha	P 30 MC 35 MP 29	4 row plot seeder
Brandon 1979	Assiniboine complex	67 kg/ha P 67 kg/ha K 22 kg/ha S	Treflan 1.1 kg/ha	P 49 MC 84 MP 97	10 row conventional drill
1980	same as 1979	same as 1979	Treflan 1.1 kg/ha Basagran .82 kg/ha (4 app)	P 44 MC 38 MP 20	same as 1979
Dauphin 1979	Dauphin clay	194 kg/ha 16-20-0	Treflan 1.1 kg/ha	P 21 MC 22 MP 21	4 row plot seeder
1st seeding date 1980	Edwards Association	196 kg/ha 16-20-0	Treflan 1.1 kg/ha	P 27 MC 24 MP 12	same as 1979
2nd seeding date 1980	Edwards Association	196 kg/ha 16-20-0	Treflan 1.1 kg/ha	P 45 MC 55 MP 24	same as 1979

[#] Desired plant densities were:
90 plants/m^2 for Maple Presto (MP).
70 plants/m^2 for McCall (MC), and Portage (P).

3.2 MEASUREMENTS

3.2.1 PHENOLOGICAL OBSERVATIONS

Climatic parameters affect soybean growth differently at different stages. In order to test their effect it was necessary to determine when specifically defined growth stages were reached. This was achieved by making weekly observations on each site and determining the stage of development of the plot for that day.

Ten plants per plot were tagged at the beginning of the season. These ten plants were randomly selected from the centre rows and considered representative of the whole plot. The growth stage of each plant was determined by standards graphically outlined in a special report by Fehr and Caviness (1977). Vegetative stages are described in Table 3. Reproductive stages are described in Table 4. A plot was regarded to have reached a given stage of growth when 50% of the plants (5 of the 10 tagged plants) had achieved that stage.

Problems arise when observations can only be made on a weekly basis. Rarely was a plot exactly at the end of a stage on the day that the observation was made. There were times when as many as three or four different stages were recorded for a particular plot. It was necessary to interpolate when the stage had been reached between the two observations. A mathematical procedure was used to establish this date. It is

TABLE 3

Description of vegetative stages of soybeans.

Stage no.	Title	Description
VE	Emergence	Cotyledons above the soil surface.
VC	Cotyledon	Unifoliate leaves unrolled sufficiently so the edges are not touching.
V1	First node	Fully developed leaves at unifoliate nodes.#
V2	Second node	Fully developed trifoliate leaf at node above the unifoliate nodes.
V3	Third node	Three nodes on the main stem with fully developed leaves beginning with the unifliate leaves.
V(n)	nth node	n number of nodes on the main stem with fully developed leaves.

A node is considered to be fully developed when the leaf above it is sufficiently unrolled so the leaf edges are not touching.

TABLE 4

Description of reproduction stages of soybeans.

Stage no.	Title	Description
R1	Beginning bloom	One open flower at any node on the main stem.
R2	Full bloom	Open flower at one of the two uppermost nodes on the main stem with a fully developed flower.
R3	Beginning pod	Pod 5 mm long at one of the four uppermost nodes on the main stem with a fully developed flower.
R4	Full pod	Pod 2 cm long at one of the four uppermost nodes on the main stem with a fully developed leaf.
R5	Beginning seed	Seed 3 mm long in a pod at one of the four uppermost nodes on the main stem with a fully developed leaf.
R6	Full seed	Pod containing a green seed that fills the pod cavity ot one of the four uppermost nodes on the main stem with a fully developed leaf.
R7	Beginning maturity (physiological maturity)	One normal pod on the main stem that reached its mature pod color.
R8	Full maturity	95% of the pods that have reached their mature pod color.

best described by an example.

When was the R3 (beginning of pod set) stage reached?

Definition: Stage unit = 1 plant going from one stage to the next.

Observation:	July 12/1979	July 20/1979
	8 plants R2	3 plants R2
	2 plants R3	5 plants R3
		2 plants R4

1st step: How many "stage units" are necessary to reach the R3 stage (hypothetically 5-R2´s and 5-R3´s). from the July 12 observation?

3 R2´s must reach the R3 stage.

2nd step: How many "stage units" were reached from July 12 to July 20?

5 R2´s went to R3 = 5
2 R3´s went to R4 = 2
7 stage units.

3rd step: 3 "stage units" were necessary to reach the R3 stage. 7 "stage units" were achieved in the 7 day period. Therefore 3/7x7 =3 days after July 12, i.e. July 15 was the date that the R3 stage was recorded to have been reached.

The date that each plot reached each stage of growth was calculated in this manner. The four dates from the four replicates for each variety were averaged to get one date at each site for each variety. The dates for all stages of growth were established in this manner.

3.2.2 WEATHER DATA

Daily maximum and minimum temperature were obtained for each site. At all sites with the exception of Waskada, data from existing weather stations was used. In Winnipeg, Morden and Brandon the weather stations existed on the site. In Dauphin the site was within one mile of the airport where a weather station exists. A Stevenson Screen was placed in Waskada and a thermograph was used to record the temperature continuously.

Daily daylength values were determined mathematically using the procedure described by Robertson and Russelo (1968). Daylength was calculated using the following formula:

$$L = 7.639 \cos^{-1}\left(\frac{\sin a - \sin\phi * \sin\delta}{\cos\phi * \cos\delta}\right)$$

Where: L = hours of daylength
a = the solar altitude at civil twilight.
Civil Twilight is where the sun is 6 deg below the horizon.
$\sin(-6 \text{ deg.}) = -.01454$
δ = declination of the sun.
ϕ = the latitude

3.2.3 SOIL TEMPERATURE

Although soil temperature was not used in the BMTF its effect on growth, especially during the the early part of the season, is critical. Two sets of thermocouples were inserted permanently at each site to measure the soil temperature at depths of 2.5, 5.0, 10, 20, 50, 100, and 150 cm. Weekly readings were taken for each depth using a hand-held potentiometer. Temperatures were measured from planting date until harvest date.

3.2.4 SOIL MOISTURE

Because of the effect of moisture stress on yield as well as growth and development, soil moisture was measured every 2 weeks in the second year of the project. Volumetric water content of surface soil (0-5cm, 5-10cm, 10-15cm, and 15-20cm) was measured by taking soil samples and measuring the wet and dry weights as well as the volume of the sample. Four samples of each layer were taken per experiment. Two neutron moisture meter tubes(4) were installed at each site to measure sub-surface moisture levels from depths of 20 to 120 cm.

3.3 PLANT DEVELOPMENT MODELS

The BMTF has been tested in the United States to predict maturity of soybean varieties adapted to lower latitudes.

$$1 = M = \operatorname*{sum}_{S_1}^{S_2} [\{ a_1(L-a_o) + a_2(L-a_o)^2\} \{ b_1(T_1-b_o) + b_2(T_1-b_o)^2$$
$$+ d_1(T_2-b_o) + d_2(T_2-b_o)^2\}]$$

This equation predicts the amount of daily development of a crop towards the completion of a phase of development. M is the sum of these daily developments from the beginning of a phenological phase to the end. Since it is difficult to visualize M numerically it is set to one (1). Then the daily development will be a fraction and the sum of daily developments will equal 1 when the stage is complete. The "a", "b", and "d" coefficients relate the daily daylength and maximum and minimum temperature, respectively, to development. Coefficients "a_o" and "b_o" are threshold values. Other "a´s", "b´s", and "d´s" are rate coefficients that describe the rate of development per unit change in photoperiod and temperature. Because the parameters (daylength and temperature) affect development differently at different phenological stages, it is necessary to develop an independent set of coefficients for each

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(4) Nuclear Moisture Gauge model 3222
Troxler Electronics Lab. Inc.
P.O. Box 12057 Research Triangle Park N.C. 27709 U.S.A.

stage.

The objective was to use this equation as a model and test it under the climatic conditions of Manitoba using varieties adapted to this region. In order to test this model, a set of coefficients were first required. A regression computer program was developed using the temperature and daylength values for the days that the crop was at a given stage of growth at all nine stations to derive these coefficients. The procedure was used by Robertson (1968) to develop coefficients for wheat. A detailed description of the procedure and the computer program is given in Appendix A and B.

The time from emergence (VE) to physiological maturity (R7) was broken down into three periods where it was assumed that development would be influenced by temperature and daylength in the same way. (The reader is referred to Tables 3 and 4 for a detailed explanation of the abbreviations for the various stages of development.) The first period was from emergence (VE) to the beginning of flowering (R1). Beginning of flowering (R1) to the appearance of pods (R3) was the second period considered. Since flowering is such a critical period and is influenced considerably by temperature and daylength, this period was considered separately. The third period was from beginning pod (R3) to physiological maturity (R7). This included the periods of pod-fill and pod maturation. While it might have been advantageous to divide this third phase into two phases, it was felt that determining when filling was complete and when the maturation process began was somewhat difficult. It was also felt that dividing soybean development into three periods was sufficient.

Physiological maturity (R7) was used instead of full maturity (R8) for several reasons. First, and most important, physiological maturity is the time when the plant ends most of its physiological processes. By this time most of the leaves have senesced as well as abscised. What remains is for the seeds and pods to turn color as they dry down to a moisture content at which they can be harvested and safely stored. Secondly, at some stations, the varieties had reached physiological maturity (R7) but not full maturity (R8) and in order to include these stations in the calculation, physiological maturity (R7) was used.

The literature indicated that varieties adapted to more northerly latitudes may be insensitive to daylength. A similar model to the BMTF was developed which considered only the temperature phase of the BMTF to see if the varieties used in the study were insensitive to daylength. Another program was used to develop the temperature coefficients and to run the BMTF but in this case taking into account only the effects of temperature.

Chapter IV

RESULTS AND DISCUSSION

4.1 PHENOLOGICAL OBSERVATIONS

The weekly phenological data gathered for nine station years was used to establish the date that each stage of development was reached. Stage dates for all three varieties at all nine stations are presented in Appendix C. These dates were the averages of the four (three in the case of Brandon 1980) replicates. The length of time between some of the more critical stages is given in Table 5. Any blanks in the table indicate there was no data available usually due to the fact that maturity was not reached at this station. In the case of Dauphin (1980 1st date) the emergence date was not obtained for any variety. This resulted in no calculated maturity date being obtained.

The three varieties emerged at about the same time at a given station. There was some variation from station to station. This is to be expected since soil temperature and soil moisture, the two parameters with the most influence on germination and emergence, varied considerably from station to station. Soil moisture will have a marked influence on the rate and percentage of seeds germinating (Heatherly and Russell, 1979). This was evidenced by the fact that it took 38 days for the soybeans to emerge in Brandon (1980), where soil conditions were extremely dry. Surface soil moisture data is given in Appendix D. Volumetric water content (θ) at the 5 - 10 cm depth was about 15% prior to a rain

TABLE 5

Length of critical phases of development for each soybean variety

Station Variety	Length of time between stages (days) Plt - VE	 VE - R1	 R1 - R4	 R4 - R7	 R1 - R7
Winnipeg 1979					
Portage	13	35	14	37	51
McCall	11	33	18	43	61
Maple Presto	12	28	14	33	47
Morden 1979					
Portage	15	31	20	33	53
McCall	14	28	25	39	64
Maple Presto	14	26	18	31	49
Waskada 1979					
Portage	19	31	16	30	46
McCall	17	27	20	35	55
Maple Presto	18	25	12	29	41
Brandon 1979					
Portage	11	34	16	31	47
McCall	11	32	16	37	53
Maple Presto	11	26	12	30	42
Dauphin 1979					
Portage	15	35	23	-	-
McCall	13	35	24	-	-
Maple Presto	14	24	19	38	57
Morden 1980					
Portage	18	29	16	38	54
McCall	12	32	20	44	64
Maple Presto	17	26	14	31	45
Brandon 1980					
Portage	38(9)#	25	27	-	-
McCall	38(9)	27	29	-	-
Maple Presto	38(9)	23	19	-	-
Dauphin 1980(1)					
Portage	-	-	27	36	63
McCall	-	-	32	33	65
Maple Presto	-	-	23	34	57
Dauphin 1980(2)					
Portage	10	38	19	42	61
McCall	10	38	21	-	-
Maple Presto	11	29	18	35	53

The bracketed planting to emergence days for Brandon 1980 are the days from the first rain to emergence.

on June 30 with little evidence of germination. Following the rain, θ was about 28% and germination was complete 6 days after the rain. At Dauphin (2nd seeding date in 1980) volumetric water content at the same depth was 37%. It took only 11 days for 50% germination to occur. Soil moisture was measured only in 1980 resulting in data from only 3 sites being available. It was felt that this was insufficient to establish any relationship between soil moisture and days to emergence.

When moisture is not limiting, temperature is the major factor affecting the time to emergence. Rate of germination increased as temperature increased to an optimum of 30 C (Wilson, 1928). Regression analysis was performed relating rate of germination, expressed as 1/(days to emergence) to the average soil temperature at 20 cm. The temperature at the 20 cm depth was chosen because weekly readings could not be made at the same time every day and depths higher than 20 cm showed a good deal of fluctuation throughout the day. While the seed would not be found at the 20 cm depth, this depth can still give an indication of the average daily temperature above it. One divided by days to emergence instead of days to emergence was used in regression because we were attempting to establish the daily rate of development based on temperature. The resulting regression equations predicted the value of 1/(days to emergence) at each station for each variety. They are given in the following equations.

Portage $1/D = .02548 + .00394(T)$

McCall $1/D = .03838 + .00353(T)$

Maple Presto $1/D = .03899 + .00303(T)$

where D = days to emergence

T = average soil temperature a 20 cm.

The slope coefficients for all three varieties are very similar indicating similar rates of germination. The predicted date of emergence was calculated by taking the reciprical of these values.

Table 6 shows the soil temperatures, observed and predicted dates of emergence along with the resulting R^2 value for the regression of temperature versus 1/days. While the R^2 were not particularly high the predicted and observed days to emergence were generally within several days of one another. Only in the cases of Portage and Maple Presto at Morden 1980 did the predicted day vary considerably from the observed day. It was concluded that the model developed adequately estimated the emergence date.

The varieties began to show consistant differences in the number of days from emergence to flowering (Table 5). Maple Presto was the first variety to flower at every station. It continued to reach each successive stage before the other two varieties. The length of the reproductive phase (beginning of flowering (R1) to physiological maturity (R7)) was consistently shorter than either Portage or McCall. McCall tended to flower slightly before Portage, however the reproductive phase of McCall tended to be longer.

Dunphy et al. (1979) found a positive correlation between the number of days from the full pod stage to physiological maturity stage and yield. A similar positive correlation was observed between yield and the number of days from the beginning of flowering to physiological maturity (Table 7). However the correlation was not as strong as in the study by Dunphy et al. (1979). McCall consistently had the longest reproductive period and also had the highest yield. Portage tended to

TABLE 6

Predicted versus observed dates of emergence from three regression equations.

Variety and Station	Avg. soil temp. at 20 cm. (deg C)	Observed Emergence date	Predicted Emergence date	R^2
Portage				.5110
Winnipeg 1979	10.6	05/6	06/6	
Morden 1979	10.9	12/6	12/6	
Waskada 1979	8.9	12/6	10/6	
Brandon 1979	14.0	17/6	18/6	
Dauphin 1979	9.5	22/6	23/6	
Morden 1980	15.8	27/5	21/5	
Brandon 1980	17.9	06/7	#07/7	
Dauphin 1980(2)	18.5	17/6	17/6	
McCall				.6627
Winnipeg 1979	10.6	03/6	05/6	
Morden 1979	10.9	11/6	10/6	
Waskada 1979	8.9	10/6	07/6	
Brandon 1979	14.0	17/6	17/6	
Dauphin 1979	9.5	20/6	21/6	
Morden 1980	15.8	21/5	20/5	
Brandon 1980	17.9	06/7	#07/7	
Dauphin 1980(2)	18.5	17/6	17/6	
Maple Presto				0.3909
Winnipeg 1979	10.6	04/6	06/6	
Morden 1979	10.9	11/6	11/6	
Waskada 1979	8.9	11/6	08/6	
Brandon 1979	14.0	17/6	18/6	
Dauphin 1979	9.5	21/6	22/6	
Morden 1980	15.8	26/5	21/5	
Brandon 1980	17.9	06/7	#08/7	
Dauphin 1980(2)	18.5	18/6	18/6	

Brandon 1980 calculations used the days from the first rain to emergence instead of planting date.

have a slightly shorter reproductive period and a correspondingly lower yield than McCall. At several sites Maple Presto reached full muturity where Portage and McCall did not. Maple Presto tended to outyield the other two varieties at these sites.

TABLE 7

Relationship between the length of the reproductive period and yield of the different varieties.

Station	McCall			Portage			Maple Presto		
	days from R1-R7	days from R4-R7	yield kg/ha	days from R1-R7	days from R4-R7	yield kg/ha	days from R1-R7	days from R4-R7	yield kg/ha
Winnipeg 1979	61	43	2559	51	37	1790	47	33	1809
Morden 1979	64	39	4538	53	33	3929	49	31	3107
Waskada 1979	55	35	1416	46	30	1203	41	29	864
Brandon 1979	53	37	1951	47	31	1786	42	30	1907
Dauphin 1979	-	-	1507	-	-	1318	57	38	1741
Morden 1980	64	44	3689	54	38	2927	45	31	2203
Brandon 1980#	-	-	-	-	-	-	-	-	-
Dauphin 1980(1)	65	33	1755	63	36	1628	57	34	1510
Dauphin 1980(2)#	-	-	-	61	42	-	53	35	-

Brandon 1980 and Dauphin 2nd date 1980 did not advance far enough to obtain any significant yields.

The relationship between length of the reproductive period and yield presents a constant dilema when searching for varieties that can be grown in areas such as Manitoba where the growing season is limited for soybean production. Because higher yielding varieties tend to require more days to mature, the number of frost free days becomes critical. It is therefore necessary to grow varieties which can consistently reach maturity and yet not so early that a significant number of growing days are lost. If the number of frost free days is sufficient to grow the later maturing variety such as McCall, it would be wise to do so because later maturing varieties tend to outyield earlier varieties. Risk zones must be established so as to predict, given the climatic data throughout the growing season, when a given variety should come to maturity and if it can do so prior to the first frost. If maturity can be achieved consistently in fewer days than the number of frost free days, the variety might have potential in that area. Thus a model that would consistently and accurately predict when maturity would occur was sought.

4.2 PLANT DEVELOPMENT MODEL

The biometeorological time scale formula (BMTF) (Robertson, 1968) relates development during a particular stage to daylength, maximum temperatures, and minimum temperatures. The equation expressing the intact BMTF is:

$$1 = M = \mathop{\mathrm{sum}}\limits_{S_1}^{S_2} [\{ a_1(L-a_o) + a_2(L-a_o)^2\} \{ b_1(T_1-b_o) + b_2(T_1-b_o)^2 + d_1(T_2-b_o) + d_2(T_2-b_o)^2\}] \qquad (1)$$

The reader is referred to page 26 for an explanation of the equation.

4.2.1 INTACT BIOMETEOROLOGICAL TIME SCALE FORMULA

Iterative regression analysis yielded a set of coefficients required for the intact BMTF (equation 1 above). A set of coefficients for each of three stages of development was derived for each variety (Table 8). The biological interpretation of the coefficient a_o is that it is an estimate of the critical daylength in hours above which there should theoretically be no development. (Soybeans are generally characterized as short day plants.) Coefficient b_o is the critical temperature below which there should be no development. It must be realized that these are statistical quantities and so one must be cautious about attaching any biological significance to them. The values calculated are simply the numerical values that best fit the data.

Close examination of the daily rates of development indicates that these coefficients are characteristic of each variety. Table 9 compares daily rates of development of the three varieties during the phase from emergence to beginning of flowering at two photoperiods and two temperatures. Coefficients from Table 8 were used in the calculation. Comparison of the change in development with a unit increase in daylength (1 hr) at a maximum temperature of 20C and minimum temperature of 10C shows that the change in daily rate of development was positive for Maple Presto, negative for Portage, and highly negative for McCall. This is consistent with other characteristics of the three varieties. As was previously mentioned, Maple Presto tended to mature the earliest followed by Portage and then McCall. Later maturing varieties tend to be more sensitive to daylength than early varieties (Polson, 1972). This would then account for the larger magnitude of change in rate of development for McCall as a result of increasing the daylength. It would

TABLE 8

Iterative regression analysis coefficients for the BMTF derived from nine (9) station years of data.

Variety	Regression Coefficients							
	Daylength			Temperature				
	ao	a1	a2	bo	b1	b2	d1	d2
Portage								
VE-R1	17.53	$-.7053\times10^{-4}$	$.8683\times10^{-7}$	-13.13	14.92	-.1653	-21.93	.4030
R1-R3	17.51	$-.3067\times10^{-1}$	0.0	25.09	2.431	-.2961	0.0	0.0
R3-R7	11.78	$.1088\times10^{-2}$	$-.2195\times10^{-3}$	12.50	3.664	-.1447	.3721	.1208
McCall								
VE-R1	20.58	$-.1975\times10^{-3}$	0.0	7.617	3.889	$-.9376\times10^{-1}$	0.0	0.0
R1-R3	12.33	$.5839\times10^{-7}$	$-.1026\times10^{-7}$	2.300	49520.	0.0	41130.	-1823.
R3-R7	13.10	$.9422\times10^{-3}$	$-.3252\times10^{-3}$	10.45	7.236	-.2639	0.0	0.0
Maple Presto								
VE-R1	20.19	-.1130	$-.5419\times10^{-2}$	10.22	$.9985\times10^{-2}$	$-.1726\times10^{-3}$	0.0	0.0
R1-R3	11.02	.1465	$-.1701\times10^{-1}$	9.944	$.0239\times10^{-1}$	0.0	0.0	0.0
R3-R7	20.31	$-.7773\times10^{-2}$	$-.6128\times10^{-3}$	7.788	$.6601\times10^{-1}$	0.0	0.0	0.0

also be expected to be negative because later maturing varieties tend to be more responsive to short dayslength (Polson, 1972; Johnston *et al.*, 1960). Portage tended to show an intermediate response in the change in rate of daily development. However, the negative change in rate of development would indicate some response to daylength. Maple Presto showed a positive change in rate of development when daylength was increased. This would seem to indicate that this variety is insensitive to daylength. The positive increase in rate of development could be accounted for by the fact that the increased amount of solar radiation increased total photosynthesis on a given day.

TABLE 9

Comparison of daily contribution of daylength and temperature terms to the BMTF and the change in rate of development for a unit increase in daylength or temperature during the emergence to flowering phase

	Maple Presto	Portage	McCall
Daylength	Daily contribution of daylength to the BMTF.		
L = 15 hr	.23	$2.506x10^{-3}$	$11.2x10^{-3}$
L = 16 hrs	.33	$1.502x10^{-3}$	$9.2x10^{-3}$
$(\ M/\ L)(dM/dt)_{T=20,10}$#	$3.252x10^{-3}$	$-21.418x10^{-3}$	$-67.62x10^{-3}$
Temperature	Daily contribution of temperature to the BMTF.		
Tmax = 20 Tmin = 10	.0813	21.333	33.81
Tmax = 21 Tmin = 10	.0876	25.03	35.28
$(\ M/\ T)(dM/dt)_{L=15}$##	$1.808x10^{-3}$	$9.49x10^{-3}$	$16.43x10^{-3}$

This expresses the change in rate of development as a result of increasing daylength from 15 to 16 hrs when maximum is held constant a 20C and minimum temperature is held constant at 10C.

This expresses the change in rate of development as a result of increasing temperature from 20 to 21 degrees C when daylength is held constant at 15 hrs.

The same trends existed when the change in rate of development was calculated for a unit increase in temperature (1 deg C) while keeping daylength constant. McCall showed the greatest response to a 1 degree C change in temperature. Portage showed an intermediate response and Maple Presto showed the least response.

These results have important implications on the potential for soybean production in Manitoba. As we move further north, daylength during the growing season is longer and temperature is lower. Rate of development of McCall would be more severely affected while Maple Presto would be the least affected. This trend occurred in our study.

A serious problem encountered when using an iterative regression approach to determine the coefficient for the biometeorological time scale formula is that one often obtains critical values of daylength and temperature which are quite unrealistic. This occurred several times in the current study (Table 8). The literature states that a base temperature of 5 to 10 C is the critical temperature for soybean growth. This may vary according to the area of adaptation of the variety. It may be better to insert a realistic critical temperature into the formula as a constant and run the regression to obtain the other coefficients. Williams (1974) assumed a base temperature and then ran the regression and made adjustments to that temperature. This may be an improvement over the present method.

Another problem exists with the calculated critical daylength value. Robertson (1968) stated that daily values below critical environmental values should be zeroed thus causing the summation for that day to be zero. However, the critical daylength value is an unrealistic value and development may occur below or above the value. Therefore, only if the entire daylength term was less than zero was the daylength term zeroed. This rarely occurred because the linear and/or quadratic coefficients were adjusted within the program so that few or none of the days would be rejected.

Temperature cannot be treated in this manner. There is clearly a critical temperature below which development ceases. Days when the maximum temperature did not reach the critical temperature were then rejected. A high critical temperature such as in the case of Portage during the flowering (R1) to beginning pod (R3) phase could result in numerous days being rejected.

The quality of the coefficients can be determined by the coefficient of variation of the calculated sums of daily development during a phase of development. This sum should be very close to one. A slight degree of error is introduced by the fact that the sum must be greater than or equal to 1 and so the mean sums tend to be slightly greater than 1. Table 10 shows the coefficient of variation (C.V.) of the sums. The coefficient of variation tended to be low for the emergence to flowering (VE-R1) and beginning pod to physiological maturity (R3-R7) phases but was considerably higher for the flowering (R1-R3) phase. Williams (1975) noted that the coefficient of variation tended to be higher for the shorter phases because of a reduction in relative precision due to measuring the length of the phase to the nearest day. This would account for the higher coefficient of variation in the flowering (R1-R3) phase.

TABLE 10

Coefficients of variation for the sums of daily development using the derived coefficients for each phase.

Variety	Coefficient of variation		
	VE-R1	R1-R3	R3-R7
Portage	6.08%	42.86%	4.75%
McCall	10.38%	19.09%	2.86%
Maple Presto	1.99%	20.91%	4.60%

4.2.2 MODIFIED BIOMETEOROLOGICAL TIME SCALE USING TEMPERATURE COEFFICIENTS ALONE.

The assumption that temperature and daylength play a significant role in development comes into question when growing varieties that have been found to be daylength insensitive for numerous characteristics (Shanmugasundarum, 1979; Major, 1980). The daylength term of the BMTF was set to unity and regression was performed on the data. The resulting temperature coefficients are given in Table 11.

The coefficient of variation (C.V.) for the sums of daily development using the temperature coefficients in the modified version of the BMTF are shown in Table 12. They were slightly higher than when using the sums derived from the original formula using temperature and daylength coefficients (Table 10) in every case except for the flowering to beginning pod (R1-R3) phase for Portage variety. In this case the C.V. was about half of that when temperature and daylength were considered. The reason for this is not readily apparent. If there were no relationship between development and daylength we would expect that both sets of

TABLE 11

Regression coefficients for the temperature phase of the BMTF.

Variety	Regression Coefficients Temperature				
	bo	b1	b2	d1	d2
Portage					
VE-R1	17.28	$.1096\times10^{-1}$	$-.6404\times10^{-3}$	0.0	0.0
R1-R3	-1.053	$.3074\times10^{-2}$	0.0	0.0	0.0
R3-R7	8.50	$.3124\times10^{-2}$	$-.8881\times10^{-4}$	0.0	0.0
McCall					
VE-R1	18.11	$.1222\times10^{-1}$	$-.7374\times10^{-3}$	0.0	0.0
R1-R3	-77.03	$.7277\times10^{-3}$	0.0	0.0	0.0
R3-R7	-109.9	$.1636\times10^{-3}$	0.0	0.0	0.0
Maple Presto					
VE-R1	13.69	$.5546\times10^{-2}$	$-.1612\times10^{-3}$	0.0	0.0
R1-R3	9.602	$.6131\times10^{-2}$	0.0	0.0	0.0
R3-R7	5.077	$.1340\times10^{-2}$	0.0	0.0	0.0

C.V.'s would be about equal. A partial explanation may be that the critical temperature derived in the first case was 25.09 C. This phase of development is already comparatively short and now there is the possibility of losing more days from the calculation of the coefficients because of the high critical temperature. As was noted earlier, the coefficient of variation tends to be higher when the number of days included in the calculation is small. The critical temperature for the modified method was less than zero resulting in none of the days being excluded from the calculation.

TABLE 12

Coefficients of variation for the sums of daily development using coefficients in a modified biometeorological time scale using temperature alone.

Variety	Coefficient of variation		
	VE-R1	R1-R3	R3-R7
Portage	14.02%	22.23%	7.03%
McCall	12.47%	22.82%	8.15%
Maple Presto	3.95%	21.16%	5.07%

/

4.2.3 USE OF DERIVED COEFFICIENTS IN PREDICTING STAGE COMPLETION

The usefulness of the coefficients is better illustrated by putting then to use in the BMTF. For each phase a predicted ending date was calculated. Tables 13,14, and 15 compare the predicted ending dates of the individual phases using the temperature and daylength coefficients, and temperature coefficients alone to the observed dates for the three varieties considered. In all cases the mean difference of the predicted minus the actual ending date was negative (Table 16). This bias is expected due to the bias introduced into the coefficient derivation as a result of the fact that the sum of daily development is greater than 1.0. As a result, the BMTF is calculating more daily development than is actually being observed. When this is the case, the expected day on which a stage will be reached might be slightly earlier than it should actually be. Williams (1974) noted a similar bias towards earliness.

The beginning pod to physiological maturity (R3-R7) phase at Brandon (1979) for McCall failed to give a predicted maturity date when using

TABLE 13

Calculated versus observed ending dates of individual stages using 2 methods of calculation for variety Portage.

Station	Stage			
	Observed starting date	observed ending date	calculated ending date method 1[#]	calculated ending date method 2[##]
	Emergence (VE) to Flowering (R1)			
Winnipeg 1979	05/6	10/7	09/7	05/7
Morden 1979	12/6	13/7	13/7	10/7
Waskada 1979	12/6	13/7	13/7	13/7
Brandon 1979	17/6	21/7	20/7	18/7
Dauphin 1979	22/6	27/7	26/7	19/7
Morden 1980	27/5	25/6	26/6	27/6
Brandon 1980	06/7	31/7	31/7	03/8
Dauphin 1980 1st	-	07/7	-	-
Dauphin 1980 2nd	17/6	25/7	23/7	16/7
	Flowering (R1) to Beginning pod (R3)			
Winnipeg 1979	10/7	21/7	18/7	20/7
Morden 1979	13/7	26/7	21/7	24/7
Waskada 1979	13/7	23/7	23/7	23/7
Brandon 1979	21/7	01/8	27/7	01/8
Dauphin 1979	27/7	10/8	01/8	08/8
Morden 1980	25/6	05/7	08/7	07/7
Brandon 1980	31/7	15/8	19/8	14/8
Dauphin 1980 1st	07/7	27/7	22/7	19/7
Dauphin 1980 2nd	25/7	05/8	18/8	07/8
	Beginning pod (R3) to Physiological maturity (R7)			
Winnipeg 1979	21/7	30/8	29/8	30/8
Morden 1979	26/7	04/9	31/8	03/9
Waskada 1979	23/7	28/8	30/8	30/8
Brandon 1979	01/8	06/9	08/9	08/9
Dauphin 1979	10/8	-	-	-
Morden 1980	05/7	18/8	18/8	12/8
Brandon 1980	15/8	-	-	-
Dauphin 1980 1st	27/7	08/9	04/9	05/9
Dauphin 1980 2nd	05/8	24/9	14/9	14/9

[#] Method 1 is using the intact BMTF.

[##] Method 2 is using the modified BMTF.

TABLE 14

Calculated versus observed end dates of individual stages using 2 methods of calculation for variety McCall.

Station	Stage			
	Observed starting date	observed ending date	calculated ending date method 1#	calculated ending date method 2##
	Emergence (VE) to Flowering (R1)			
Winnipeg 1979	03/6	06/7	05/7	03/7
Morden 1979	11/6	09/7	11/7	07/7
Waskada 1979	10/6	07/7	10/7	06/7
Brandon 1979	17/6	19/7	18/7	17/7
Dauphin 1979	20/6	25/7	21/7	18/7
Morden 1980	21/5	22/6	19/6	21/6
Brandon 1980	06/7	02/8	02/8	01/8
Dauphin 1980 1st	-	05/7	-	-
Dauphin 1980 2nd	17/6	25/7	19/7	15/7
	Flowering (R1) to Beginning pod (R3)			
Winnipeg 1979	06/7	20/7	19/7	19/7
Morden 1979	09/7	25/7	21/7	21/7
Waskada 1979	07/7	20/7	19/7	19/7
Brandon 1979	19/7	29/7	30/7	01/8
Dauphin 1979	25/7	08/8	06/8	07/8
Morden 1980	22/6	04/7	07/7	05/7
Brandon 1980	02/8	16/8	15/8	15/8
Dauphin 1980 1st	05/7	26/7	21/7	18/7
Dauphin 1980 2nd	25/7	05/8	07/8	07/8
	Beginning pod (R3) to Physiological maturity (R7)			
Winnipeg 1979	20/7	05/9	01/9	04/9
Morden 1979	25/7	11/9	01/9	08/9
Waskada 1979	20/7	31/8	01/9	02/9
Brandon 1979	29/7	10/9	†09/9	12/9
Dauphin 1979	08/8	-	-	-
Morden 1980	04/7	25/8	25/8	18/8
Brandon 1980	16/8	-	-	-
Dauphin 1980 1st	26/7	08/9	05/9	10/9
Dauphin 1980 2nd	05/8	-	-	-

\# Method 1 is using the intact BMTF.
\#\# Method 2 is using the modified BMTF.
† Estimated date: day after 98% of development had occurred.

TABLE 15

Calculated versus observed ending dates of individual stages using 2 methods of calculation for variety Maple Presto.

Station	Stage			
	Observed starting date	observed ending date	calculated ending date	
			method 1#	method 2##
	Emergence (VE) to Flowering (R1)			
Winnipeg 1979	04/6	02/7	02/7	02/7
Morden 1979	11/6	07/7	06/7	06/7
Waskada 1979	11/6	06/7	06/7	06/7
Brandon 1979	17/6	13/7	12/7	12/7
Dauphin 1979	21/6	15/7	15/7	14/7
Morden 1980	26/5	21/6	20/6	21/6
Brandon 1980	06/7	29/7	28/7	30/7
Dauphin 1980 1st	-	30/6	-	-
Dauphin 1980 2nd	18/6	17/7	16/7	14/7
	Flowering (R1) to Beginning pod (R3)			
Winnipeg 1979	02/7	10/7	10/7	10/7
Morden 1979	07/7	16/7	15/7	15/7
Waskada 1979	06/7	14/7	13/7	13/7
Brandon 1979	13/7	21/7	21/7	21/7
Dauphin 1979	15/7	28/7	23/7	23/7
Morden 1980	21/6	29/6	30/6	30/6
Brandon 1980	29/7	10/8	09/8	09/8
Dauphin 1980 1st	30/6	14/7	10/7	10/7
Dauphin 1980 2nd	17/7	28/7	28/7	28/7
	Beginning pod (R3) to Physiological maturity (R7)			
Winnipeg 1979	10/7	18/8	17/8	17/8
Morden 1979	16/7	25/8	20/8	21/8
Waskada 1979	14/7	16/8	16/8	16/8
Brandon 1979	21/7	24/8	24/8	25/8
Dauphin 1979	28/7	10/9	08/9	08/9
Morden 1980	29/6	05/8	03/8	02/8
Brandon 1980	10/8	-	-	-
Dauphin 1980 1st	14/7	26/8	25/8	24/8
Dauphin 1980 2nd	28/7	08/9	08/9	09/9

\# Method 1 is using the intact BMTF.
\#\# Method 2 is using the modified BMTF.

TABLE 16

Mean differences of predicted minus actual days to a given stage and standard deviations of these means with the two prediction methods.

Variety Stage	Method 1#		Method 2##	
	mean (days)	S.D.	mean (days)	S.D.
Portage				
VE -R1	-0.43	.976	-2.88	4.39
R1 -R3	-0.78	6.65	-1.11	2.98
R3 - R7	-2.14	4.26	-2.29	4.42
McCall				
VE -R1	-1.25	3.01	-3.38	3.34
R1 - R3	-0.89	2.62	-1.11	3.30
R3 - R7	-2.83	3.97	-0.83	3.66
Maple Presto				
VE - R1	-0.63	.518	-0.63	1.19
R1 - R3	-1.22	1.99	-1.22	1.99
R3 - R7	-1.38	1.69	-1.38	2.07

\# Method 1 is using the intact BMTF.
\## Method 2 is using the modified BMTF.

the intact BMTF. The date in Table 14 is an estimated date following 98% completion of that phase. The reason for this is that the critical daylength for this phase is 13.1 hours. As daylength decreases after summer solstice, the critical value is eventually reached if development is not complete by this time. The majority of actual daylength values are above this value and the other daylength coefficients have been adjusted accordingly so that development occurs above this value. When the daylength falls below this value, the whole daylength term will always be negative and the program will set the term to zero thus causing development to be zero on that day. This problem only arises at this station because all the other stations tended to slightly under-predict the maturity date while this one was slightly over predicted.

Mean differences of predicted minus actual days and standard deviations of these means that are close to zero indicate a good prediction. In most cases the means and standard deviations of the method using both temperature and daylength coefficients were closer to zero than those using temperature alone. This indicated that the inclusion of a daylength parameter probably improved the model. Only in the case of the flowering to beginning pod phase for Portage did this appear not to be the case. Reasons for this were discussed in the previous section.

The predicted ending date of the beginning pod to physiological maturity (R3-R7) phase tended to be considerably earlier than the actual date at Morden (1979) for all three varieties. Calculations for Dauphin (1979) also under-estimated the length of this period significantly for the only variety that reached maturity (Maple Presto). The reason for this under-estimation may be that these two stations were not as severely stressed by inadequate soil moisture as were the other stations in 1979 and 1980. This was a general observation and is not supported by any data. Brown and Chapman (1960) observed that development was hastened when soybeans were stressed following flowering resulting in a shortening of the period. The existing model may then include a bias towards soybeans grown under moisture stress because the majority of stations throughout the two years of research were under some moisture stress. Modifications to account for this factor will be discussed later.

4.2.4 USE OF COEFFICIENTS TO PREDICT TIME FROM EMERGENCE TO MATURITY

The regression coefficients were derived for the time from the actual beginning to the actual end of a phase. When making a prediction of maturity from emergence or planting date, we must take the calculated ending date of the preceding phase as the starting date of the next phase. Two computer programs calculated a predicted maturity date from the emergence date using the intact BMTF and the modified BMTF. The estimated maturity dates are given in Table 17. It was expected that an additional error would be introduced into the estimation of maturity because we were no longer using only the days that had been included in the calculation of the coefficients. If the calculated completion of a stage was prior to the actual day, the calculation of the next stage would begin with data that was different from that included in the derivation of the coefficients for that stage. This additional error did not appear to seriously affect the reliability of the predicted maturity date. The deviation of the calculated maturity date from the actual maturity date, appeared for the most part, to be an accumulation of the deviations from the individual phases. For example: in the case of McCall at Morden in 1980 the emergence to flowering (VE-R1) phase was under predicted by three days. The flowering (R1-R3) phase was overpredicted by three days and the beginning pod to physiological maturity (R3-R7) phase was predicted to occur on the same day as was observed (Table 14). The estimated days from emergence to maturity was exactly equal to that observed.

In general, calculated days to maturity were very close to the observed for both the intact and modified BMTF. Predicted dates of matur-

TABLE 17

Calculated versus observed dates from emergence to maturity.

Station	Variety			
	Observed emergence date	observed maturity date	calculated maturity date method 1#	calculated maturity date method 2##
	Portage			
Winnipeg 1979	05/6	30/8	28/8	26/8
Morden 1979	12/6	04/9	28/8	29/8
Waskada 1979	12/6	28/8	01/9	31/8
Brandon 1979	17/6	06/9	03/9	06/9
Dauphin 1979	22/6	-	18/9	11/9
Morden 1980	27/5	18/8	21/8	17/8
Brandon 1980	06/7	-	-	-
Dauphin 1980 1st	-	08/9	-	-
Dauphin 1980 2nd	17/6	24/9	-	06/9
	McCall			
Winnipeg 1979	03/6	05/9	01/9	30/8
Morden 1979	11/6	11/9	01/9	03/9
Waskada 1979	10/6	31/8	02/9	31/8
Brandon 1979	17/6	10/9	†12/9	13/9
Dauphin 1979	20/6	-	-	15/9
Morden 1980	21/5	25/8	25/8	17/8
Brandon 1980	06/7	-	-	-
Dauphin 1980 1st	-	08/9	-	-
Dauphin 1980 2nd	17/6	-	-	11/9
	Maple Presto			
Winnipeg 1979	04/6	18/8	17/8	16/8
Morden 1979	11/6	25/8	19/8	19/8
Waskada 1979	11/6	16/8	15/8	16/8
Brandon 1979	17/6	24/8	23/8	25/8
Dauphin 1979	21/6	10/9	29/8	30/8
Morden 1980	26/5	05/8	05/8	05/8
Brandon 1980	06/7	-	-	-
Dauphin 1980 1st	-	26/8	-	-
Dauphin 1980 2nd	18/6	08/9	07/9	05/9

Method 1 is using the intact BMTF.

Method 2 is using the modified BMTF.

† Estimated date: day after 98% of development had occurred.

ity were generally within four days of the actual date. No one particular variety was consistently predicted better using either prediction method. Mean differences of predicted minus actual dates and standard deviations of these means were quite similar for all three varieties (Table 18). All means were negative as was the case with the individual phases. The reason for this negative tendency was discussed on page 43. The prediction method using both temperature and daylength parameters usually had slightly lower means than the prediction method that considered only temperature. Differences in the standard deviations of these means, however, were only obvious for the Portage variety, where the first prediction method (using temperature and daylength) was considerably lower than the second method (using temperature only).

TABLE 18

Mean differences of predicted minus actual days from emergence to maturity and standard deviations of the means with the two prediction methods.

Variety	Prediction Method			
	Method 1[#]		Method 2[##]	
	mean (days)	S.D.	mean (days)	S.D.
Portage	-1.00	4.53	-4.33	7.39
McCall	-2.00	5.09	-3.80	5.02
Maple Presto	-3.14	4.38	-3.00	4.24

[#] Method 1 is using the intact BMTF.
[##] Method 2 is using the modified BMTF.

4.2.5 USE OF THE COEFFICIENTS TO PREDICT TIME FROM PLANTING TO MATURITY

For any model to be useful it must predict the time from planting to maturity. The BMTF was used to predict the time from emergence to maturity. In the past, the BMTF has been used to predict the phase from planting to emergence. Ambient temperature instead of soil temperature is then used to predict emergence. In the spring time, while ambient temperature can be very warm, the soil temperatures can be considerably cooler. Therefore it was felt that soil temperatures should be considered during this phase of development. The predicted emergence dates from regression analysis of 1/(days to emergence) versus soil temperature (Table 6) were used. These dates were substituted for the observed emergence dates and a predicted maturity date was obtained using the intact and modified BMTF (Table 19). It was expected that an additional error would be introduced into the calculation as a result of using the predicted emergence dates. This additional error was not readily apparent. While the mean differences of calculated minus observed dates from planting to maturity (Table 20) were slightly increased in comparison to those using observed dates of emergence (Table 18), the standard deviations of these means were generally the same or slightly less when calculating maturity from the planting date.

The question of the acceptability of the error in predicting maturity date must be considered. Eventually it is hoped that the model could be applied to historical weather data for Manitoba so that one could establish with some degree of confidence when maturity is likely to be reached and whether it can be reached prior to the first frost. However, the number of frost free days and date of the first fall frost is extremely variable. Dunlop (1981) found the standard deviation of the first fall frost and the number of frost free days to be in the order of 10-12 days and 16-20 days, respectively. These standard deviations are considerably higher than the differences between the predicted maturity date and the actual maturity date (4-5 days). One can conclude, therefore, that the variability in the weather is more of a limiting factor than the accuracy of the prediction model. It must be reemphasized, however, that the results presented here are from the test data itself. Further testing is needed on independent data to determine whether the model can actually predict maturity with the same degree of accuracy.

TABLE 19

Observed versus calculated dates from planting to maturity using two prediction methods.

Station	Variety			
	planting date	observed maturity date	calculated maturity date method 1#	calculated maturity date method 2##
		Portage		
Winnipeg 1979	23/5	30/8	28/8	26/8
Morden 1979	28/5	04/9	28/8	29/8
Waskada 1979	24/5	28/8	31/8	24/8
Brandon 1979	06/6	06/9	03/9	09/9
Dauphin 1979	07/6	-	18/9	11/9
Morden 1980	09/5	18/8	18/8	14/8
Brandon 1980	27/6	-	-	-
Dauphin 1980 1st	17/5	08/9	-	-
Dauphin 1980 2nd	07/6	24/9	-	06/9
		McCall		
Winnipeg 1979	23/5	05/9	30/8	01/9
Morden 1979	28/5	11/9	31/8	02/9
Waskada 1979	24/5	31/8	30/8	31/8
Brandon 1979	06/6	10/9	†12/9	13/9
Dauphin 1979	07/6	-	-	15/9
Morden 1980	09/5	25/8	25/8	18/8
Brandon 1980	27/6	-	-	-
Dauphin 1980 1st	17/5	08/9	-	-
Dauphin 1980 2nd	07/6	-	-	11/9
		Maple Presto		
Winnipeg 1979	23/5	18/8	20/8	16/8
Morden 1979	28/5	25/8	19/8	19/8
Waskada 1979	24/5	16/8	11/8	12/8
Brandon 1979	06/6	24/8	23/8	25/8
Dauphin 1979	07/6	10/9	01/9	30/8
Morden 1980	09/5	05/8	28/7	28/7
Brandon 1980	27/6	-	-	-
Dauphin 1980 1st	17/5	26/8	-	-
Dauphin 1980 2nd	07/6	08/9	07/9	05/9

Method 1 is using the intact BMTF.

Method 2 is using the modified BMTF.

† Estimated date: day after 98% of development had occurred.

TABLE 20

Mean differences of predicted minus actual days from planting to maturity and standard deviations of the means with the two prediction methods.

Variety	Prediction Method			
	Method 1#		Method 2##	
	mean (days)	S.D.	mean (days)	S.D.
Portage	-0.20	2.39	-5.50	6.86
McCall	-3.20	5.26	-3.40	4.93
Maple Presto	-4.00	4.08	-4.71	3.99

Method 1 is using the intact BMTF.
Method 2 is using the modified BMTF.

Chapter V

CONCLUSIONS

Temperature would appear to be the major factor affecting growth and development of soybeans in Manitoba. The modified BMTF considering only temperature provided a reasonable estimate of maturity on the test data. The inclusion of a daylength parameter improved the prediction leading to the conclusion that it too has a significant effect on development.

The derived coefficients for the BMTF were satisfactory to provide a fairly good estimate of maturity for the nine stations considered. Regression analysis of 1/(days to emergence) versus soil temperature provided an adequate estimate of emergence so that this could be combined with the BMTF estimation to get an estimated maturity date from the planting date. Further testing with more soil temperature data would improve the prediction of emergence. Research is presently being conducted at the University of Manitoba to predict soil temperatures from air temperatures. This information might be useful in improving our prediction of emergence.

The errors in estimating date of crop maturity were less than one-half the standard deviations of the date of the first frost and length of frost free period recorded at weather stations in Manitoba. On the basis of this information, it was concluded that the error in estimating maturity date would not be a limiting factor in using the model to estimate the potential for soybean production in the various regions of Manitoba.

Nine station years of data is an insufficient base on which to build a model. Increasing the number of stations to include a wider variety of climatic variation is necessary. A bias may have been introduced because most of the stations suffered from moisture stress. With the expansion of the number of stations, moisture must then be considered as a third parameter affecting development of soybeans. Once the base has been increased sufficiently the model must be tested on independent data. Only then will it be possible to draw conclusions about the prediction capability of the model.

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Appendix A

DESCRIPTION OF THE PROGRAM TO DERIVE COEFFICIENTS FOR THE BIOMETEOROLOGICAL TIME SCALE FORMULA

A.1 INTRODUCTION

A computer program was received from the Agmet Section of the Land Resource Research Institute in Ottawa (Appendix B). This program derives a set of coefficients that can be inserted into the biometeorological time scale formula (BMTF) (Robertson, 1968). With the use of these coefficients, the formula should predict with some accuracy, the daily development of the crop at a given growth stage on the basis of daily maximum and minimum temperatures and daylength values. Ultimately, it is desirable to predict the time from planting date or emergence to maturity for the crop in question (soybeans). To derive these coefficients, regression analysis is performed on a set of observed data.

If the BMTF (Equation 1) is manipulated mathematically, two different equations (3 and 4) can be obtained.

$$1 = M = \underset{S_1}{\overset{S_2}{\text{sum}}} \; [\{ a_1(L-a_o) + a_2(L-a_o)^2\} \{ b_1(T_1-b_o) + b_2(T_1-b_o)^2 + d_1(T_2-b_o) + d_2(T_2-b_o)^2\}] \qquad (1)$$

(simplification of equation 1)

$$1 = \mathrm{sum}_{S_1}^{S_2}[V_1(V_2 + V_3)] \qquad (2)$$

where: V_1 = contribution of photoperiod to daily rate of development.
V_2 = contribution of maximum temperature to daily rate of development.
V_3 = contribution of minimum temperature to daily rate of development.

$$1/\mathrm{sum}V_1 = P_o + P_1(\mathrm{sum}(V_1T_1)/\mathrm{sum}V_1 + P_2(\mathrm{sum}(V_1T_1{}^2)/\mathrm{sum}v_1 + P_3(\mathrm{sum}(V_1T_2)/\mathrm{sum}V_1 + P_4(\mathrm{sum}(V_1T_2{}^2)/\mathrm{sum}V_1 \qquad (3)$$

$$1/\mathrm{sum}(V_2{+}V_3) = q_o + q_1\mathrm{sum}(V_2{+}V_3)L/\mathrm{sum}(V_2{+}V_3)) + q_2(\mathrm{sum}(V_2{+}V_3)L^2/\mathrm{sum}(V_2{+}V_3)) \qquad (4)$$

The "q" and "p" coefficients are functions of the "a" and "b" coefficients, respectively, as described in equations 5-12.

$$a_o = [-q_1 \pm \mathrm{SQRT}(q_1{}^2-4q_oq_2)]/2q_2 \qquad (5)$$

$$a_1 = q_1 + 2q_2a_o \qquad (6)$$

$$a_2 = q_2 \qquad (7)$$

$$b_o = -(p_1+p_3) \pm \mathrm{SQRT}((p_1+p_3)^2-4(p_2+p_4)p_o)/2(p_2+p_4) \qquad (8)$$

$$b_1 = p_1 + 2p_2b_o \qquad (9)$$

$$b_2 = p_2 \qquad (10)$$

$$b_3 = p_3 + 2p_4b_o \tag{11}$$

$$b_4 = p_4 \tag{12}$$

Regression analysis can be applied to equation 3 if the coefficients in V1 (the light phase) are implied. A set of "p" regression coefficients are obtained and from them we can obtain a set of temperature (b) coefficients that are somewhat related to the data. If these temperature coefficients are then used in V2 and V3, regression analysis can be applied to equation 4. Light coefficients can then be calculated from the resulting "q" regression coefficients. This new set of light coefficients now replaces the first set and regression is again performed on equation 3. This time, however the V1 values should "fit" the data better because of the improved light coefficients and the resulting temperature coefficients should also "fit" better. The process of performing regression analysis on equations 3 and 4 will continue until the resulting coefficients are not altered significantly.

The program then follows this procedure of applying regression analysis to equation 3 and 4 alternatively. A limit of thirty iterations was set, assuming that the change in the coefficients would not be significant after this.

The original program we received was one which Williams (1974) had used to derive a set of coefficients for barley. It was necessary to make numerous changes in the inputting and storing of the data. As well, there were several areas in the program where the the procedure was different from that used by Robertson (1968). Changes were made, and will be noted in the explanation that follows.

While a set of variable definitions are in the program, a description of the function of each section of the program will be useful for future research.

A.2 DESCRIPTION OF PROGRAM SECTION BY SECTION

The program will derive a set of regression coefficients for a given stage of development. The date that the stage begins and ends is read in from a data file. Maximum and minimum temperatures as well as the daylength for each day from the beginning to the end of the stage are also read from a data file. Information from each relevent station is saved and used in the regression. The first 186 lines define the variables and arrays and give the dimensions.

A.2.1 LINES 187-243

These lines read in data from 3 different sources as follows:

A.2.1.1 A CONTROL FILE (lines 187-193)

The program reads a title, the phase (either light or temperature), the coefficients, the variety of soybeans, the stage to begin and end with, the number of iterations, the order in which to perform the iterations (i.e. run regression on temperature phase and then the light phase alternating back and forth), and the last date that will be considered.

A.2.1.2 GROWTH STAGE DATES (lines 194-212)

Three different files containing all growth stage dates from all stations for a given variety are used. The stage is assumed to end when the next stage begins. Hence if we want to do the calculation from emergence to flowering we would take the observed date of emergence as the beginning of the stage and the observed flowering date as the end of the stage. The program reads in all 12 stages that were observed at a given station for a particular variety into the array LESTAG(I). Array IBEGIN(I) takes the value for LESTAG(IFIRST). Array IEND(I) takes the value for LESTAG(LAST). If either value equals zero then the station is not considered in the calculation.

A.2.1.3 DAILY METEOROLOGICAL DATA (213-223)

The third source reads the meteorological data (daily maximum and minimum temperatures and daylength values). The data from all nine station years from May 1 to Sept. 30 is contained in a file. Only the data from the dates IBEGIN(I) to IEND(I) for each station is retained and used in the calculation. It is stored in 3 two-dimensional arrays. The first subscript in the array is the station indicator and the second subscript is the date. The station indicator is a number that indicates a location of the station and the year in which the data was gathered.

A.2.2 LINES 224-285

This section saves and prints out the relevent climatic data. The original program didn´t save the data but rather printed it onto tape and then read it off the tape when necessary. With the facilities available at the University of Manitoba, it was more practical to store the data in three arrays instead. The data is also averaged and summed.

A.2.3 LINES 289-302

In this section variables are zeroed and the order in which the iterations will be performed is specified. The mode should alternate from the light to the temperature phase after each iteration.

A.2.4 DO LOOP 670 (lines 308-669)

Each time through this loop is one iteration. Regression analysis is performed and a new set of light or temperature coefficients are derived. These presumably fit the data better than the previous set of coefficients.

Lines 318-335 is a section where all values used in the main loop (670 loop) are defined.

A.2.4.1 LINES 336-341

This section is a control centre that is referred to at different times throughout the program and directs the program in the right direction. If the program was performing regression on the temperature term then certain specified areas of the program were used. Similarly, if the program was performing regression on the daylength term, then other areas of the program were used.

A.2.4.2 DO LOOP 430 (lines 347-474)

This loop considers each station separately. Daily calculations are performed within this loop for each day that the crop was at a given stage at a given station.

DO LOOP 300 (lines 364-426)

This loop calculates the amount of daily development that should have occurred using the latest set of coefficients (lines 365-399). SUMK (line 399) is the sum of daily developments for a given station. If the coefficients are correct then SUMK should be close to 1.0 when NODAY=IMXDAY. IMXDAY is the length of the particular stage at a particular station. Following line 399 this loop can take one of 2 paths depending on which phase the program is in. If it is in the light phase only ACCUM1-ACCUM3 values are calculated. ACCUM1 and ACCUM2 values represent sum((V2+V3)xL) and sum((V2+V3)L^2) respectively. ACCUM3 is the sum of V2+V3. If the program is in the temperature phase it will calculate ACCUM1-ACCUM5 values. ACCUM1-ACCUM4 values represent sum(V1xT_1), sum(V1xT_1^2), sum(V1xT_2), sum(V1xT_2^2) respectively.

Following the daily looping, the 430 do loop continues. Lines 442-456 calculate X(I) values using the ACCUM sums calculated for that station. X(I) is a calculation of a separate value for the different segments of equation 3 or 4. For example, X(I) in the temperature phase is the sum(V1xT1)/sumV1. Lines 465-468 then sum these X(I) values for each station resulting in SX(I) values. This is illustrated below for the light phase. The temperature phase would be similar but would correspond to segments in eqn. 3.

X(1) = sum((V2+V3)xL)/sum(V2+V3) in Eqn. 4.

X(2) = sum((V2+V3)xL^2)/sum(V2+V3) in Eqn. 4.

X(3) = 1./sum(V2+V3) left side of Eqn. 4.

SX(I) = sum(X(I)) for all stations under consideration.

SSX(I,J) = sum of the cross products of X(I) for all stations under consideration.

These SX(I) and SSX(I,J) are the sums and sums of products that are used in the regression subroutine later on in the program (line 512).

A.2.4.3 REGRESSION ANALYSIS (lines 486-512)

After line 479 the program prepares for the actual regression analysis. The SX values go through a series of checks prior to the analysis. If their values are less than or equal to zero they are appropriately modified. The actual regression analysis occurs in a subroutine (lines 680-717). The SX,SSX, and AC arrays in the main program are common to the subroutine and therefore do not have to be included in the call statement (line 512).

The subroutine carries out the actual regression analysis. A set of regression coefficients are calculated for equations 3 or 4 depending upon the mode of the iteration. These values are stored in the subroutine array A(I). This array is common to the main program array AC(I) and corresponds to the "p" or "q" regression coefficients in equations 3 or 4.

A.2.4.4 CALCULATION OF "a" OR "b" COEFFICIENTS FROM "p" OR "q" COEFFICIENTS (lines 545-624)

The new "a" or "b" coefficients are calculated using the calculated "p" ar "q" coefficients from the regression analysis. Values for light coefficients (a) are related to "q" values by equations 5-7. Temperature coefficients are related to "p" coefficients by equations 8-12. These calculations are carried out in lines 263-293. If WORK (line 546) is negative resulting in the square root of WORK (line 554) being undifined, "ao" or "bo" coefficients could not be calculated. The program then makes an adjustment of the SX and SSX values (lines 584-595) and does another regression on the same data (line 599). The "a" and "b" coefficients are calculated slightly differently (lines 608-624).

A.2.4.5 CALCULATION OF COEFFICIENT OF VARIABILITY (lines 628-634)

A coefficients of variability is calculated on the SUMK values for each station. Theoretically the SUMK values should all be very close to 1.0 if the coefficients for that iteration were accounting for most of the variation from station to station. The quality of the coefficients is dependent on whether the parameters being considered can account for the variation in growth from station to station. The coefficient of variability then tells us something about the quality of the data which has been collected and whether the variation from station to station can be accounted for with these climatic parameters.

A.2.4.6 REDEFINING OF THE COEFFICIENTS (lines 638-669)

The ACCUM1-ACCUM5 values calculated in lines 545-624 are used to define either the light coefficients or the temperature coefficients, but not both. The original program made adjustments to the base temperature (bo) or base daylength (ao). However, this would not seem to be in order with the technique that Robertson (1968) used. Therefore this was changed so that the new base temperature or daylength value was that value calculated from regression analysis.

A.2.4.7 END OF PROGRAM

After the required number of iterations are completed, the program comes to completion. A set of coefficients should have been calculated that are the best possible for the stage under consideration. It should be noted that the program did not always perform the required (stated) number of iterations. Because constant adjustments were always taking place and an old set of light coefficients along with a new set of temperature coefficients resulted periodically in V1, V2, and V3 values that were so far off that the program failed after a number of iterations. It was still possible, however to look at those coefficients which were derived and to pick a set with a low coefficient of variability and use these coefficients.

Appendix B

COMPUTER PROGRAM TO DERIVE COEFFICIENTS FOR THE BIOMETEOROLOGICAL TIME SCALE FORMULA.

```
 1. //AGROMETE JOB ´0075,SIN,98,T=30,L=3´,´G FALK´,MSGLEVEL=1
 2. /*TSO SOIL
 3. // EXEC WATFIV,SIZE=500K
 4. //GO.SYSIN DD *
 5. $JOB WATFIV
 6. C
 7. C THIS PROGRAM CALCULATES A SET OF COEFFICIENTS FOR A GIVEN OF
 8. C A CROP THAT CAN BE USED IN THE BIOMETEOROLOGICAL TIME SCALE
 9. C FORMULA. THE COEFFICIENTS ARE DERIVED USING REGRESSION ANALYSIS
10. C ON AN OBSERVED SET OF DATA.
11. C
12. C DEFINITIONS OF VARIABLES AND ARRAYS IN ALPHABETICAL ORDER.
13. C
14. C VARIABLES
15. C
16. C ACCUM1 TO ACCUM5= ARE ACCUMULATED VALUES FOR DIFFERENT
17. C         COMPONENTS OF THE DAILY DEVELOPMENT CALCULATION.
18. C         LIGHT PHASE
19. C ACCUM1= SUM(V1+V2)*L)
20. C ACCUM2= SUM(V2+V3)*L*L)
21. C ACCUM3= SUM(V2+V3)
22. C         TEMPERATURE PHASE
23. C ACCUM1= SUM(V1*T1)
24. C ACCUM2= SUM(V1*T1*T1)
25. C ACCUM3= SUM(V1*T2)
26. C ACCUM4= SUM(V1*T2*T2)
27. C ACCUM5= SUM(V1)
28. C AVGK  = THE AVERAGE SUMK VALUE FOR ALL THE STATIONS CONSIDERED.
29. C         IT IS USED TO CALCULATE THE COEFFICIENT OF VARIABILITY.
30. C A1, A2, A3, IA1,IA2,IDIV, =VARIABLES USED IN THE AVERAGING
31. C         THE TEMPERATURES AND DAYLENGTH DURING THE TIME FROM
32. C         BEGINNING TO ENDING THE STAGE.
33. C CASE  = A VARIABLE THAT COUNTS THE NUMBER OF STATIONS USED
34. C         IN THE CALCULATION
35. C CONTCV= THE NUMBER OF STATIONS; OR THE NUMBER OF SUMK VALUES
36. C         FOR THE CALCULATION OF THE COEFFICIENT OF VARIABILITY.
37. C COVAR = IS THE COEFFICIENT OF VARIABILITY.
38. C HEADNG= AN ALPHA NUMERIC THAT READS A HEADING OF A DATA
39. C          FILE.
40. C IFIRST= IS A NUMBER FROM 1=11 THAT TELLS US WHICH GROWTH
41. C         STAGE TO BEGIN WITH.
42. C IMXDAY= EQUALS MXDAYS(KOT); LENGTH OF THE STAGE( IN DAYS)
43. C         FOR STN NO. KOT.
44. C ISET  = IS A VALUE THAT COUNTS AND DESIGNATES WHERE TO IN
45. C         LINES 243=260.
46. C ITEST1= EQUALS IBEGIN(I) AND IS USED TO INDICATE AFTER
47. C         WHICH DATE THE CLIMATIC DATA SHOULD BEGIN TO BE
48. C         TAKEN FROM ITEMP1(I) TO ITEMP(KOT,I) ETC.
49. C ITEST2= EQUALS IEND(I) AND INDICATES AT WHICH DATE TO STOP
50. C         COLLECTING CLIMATIC DATA IN THE 3, TWO DIMENSIONAL
51. C         ARRAYS ITEMP, IOUTXN, AND OUTDAY.
52. C ITTER = INDICATES THE PHASE. 1=LIGHT, 2=TEMPERATURE
53. C IY    = A CHECK (LINE 84) TO SEE IF ALL STATION DATA HAS BEEN
54. C         READ.
```

```
C KNOB   = THIS VARIABELE IS STRATEGICALLY PLACED SO THAT IF
C          YOU'RE CALCULATING THE DAYLENGTH COEFFICIENTS YOU
C          WILL BE IN A CERTAIN AREA. THEN KNOB=3; IF IN
C          TEMPERATURE MODE KNOB=5, FOR 5 COEFFICIENTS TO
C          BE CALCULATED.
C          THE VALUE OF KNOB IS ALSO USED AS A VBALUE THAT
C          IS PASSED TO THE SUB=ROUTINE.
C KNTR1  = A COUNTING VARIABLE FOR ARRAYS ITEMP1, ITEMP2, DAY.
C KNTR2  = A COUNTING VARIABLE THAT COUNTS THE NUMBER OF DAYS
C          BETWEEN IBEGIN AND IEND FOR EACH STATION.
C KOT    = A COUNTING VARIABLE USED AS A STN IDENTIFIER.
C KOUNT  = A COUNTING VARIABLE THAT COUNTS THE NUMBER OF STATIONS
C          THIS NUMBER SHOULD ALWAYS EQUAL 9 WHILE CASE SHOULD
C          BE LESS THAN OR EQUAL TO 9. IT ALSO IS USED AS A
C          STN IDENTIFIER LATER ON.
C KOUNT1 TO KOUNT7= COUNT THE NO OF DAYS THAT VONE,VTWO,
C          VTHREE, AND VFOUR WERE DEFAULTED
C KY     = INDICATES  THE NUMBER OF THE LAST STATION
C LAST   = A NUMBER FROM 1=11 THAT TELLS US WHICH STAGE TO END
C          WITH.
C LASTDT= DAYS ARE NUMBERED FROM MAY 1 (122) TO SEPT 30 (274)
C          (NOTE 1980 WAS A LEAP YR). LASTDT=274 IN OUR CASE.
C LASTYR= FOR OUR PURPOSE THIS IS THE LAST STN YR. IE.09.
C LECROP= A CROP VARIETY IDENTIFIER THAT MUST CORRESPOND TO
C          IDCROP.
C LIST   = NO OBVIOUS PURPOSE. WILL BE DELETED LATER.
C MXITER= MAXIMUM NUMBER OF ITTERATIONS. (30).
C MXPLNT= EQUAL TO CASE BUT NOW INTEGER;NUMBER OF STNS
C          CONTAINING DATA RELAVENT TO THE GROWTH STAGE IN QUESTION.
C NOITER= COUNTING VARIABLE IN DO LOOP 670 INDICATING THE
C          NUMBER OF THE ITTERATION BEING PERFORMED.
C NOPLNT= COUNTING VARIABLE FOR DO LOOP 430; IS ANOTHER STN
C          INDICATOR.
C NOREG  = EQUAL MXPLNT; NO. OF REGRESSIONS TO BE PERFORMED?
C OPDAY  = THE OPTIMUM DAYLENGTH CALCULATED WITH THE LAST SET
C          OF COEFFICIENTS.
C OPMAX  = THE OPTIMUM MAXIMUM TEMPERATURE CALCULATED WITH
C          THE LAST SET OF COEFFICIENTS.
C OPMIN  = THE OPTMIMUM MINIMUM TEMPERATURE.
C SUMK   = IS THE TOTAL OF VONE*VFOUR FOR EACH STATION. WHEN
C          SUMK EQUALS 1 OR CLOSE TO 1 THEN DEVELOPMENT FOR
C          THAT STAGE WHOULD BE COMPLETE. (EQUIVELENT TO M
C          IN EQUATION 5 OF ROBERTSON'S PAPER). THIS SHOULD BE
C          TRUE IF THE COEFFICIENTS ARE THE RIGHT ONES.
C SUMKS  = THE SUM OF SUMK'S FOR ALL STATIONS.
C SUMKSS= THE SUM OF (SUMK)SQUARED FOR ALL STATIONS.
C
C ALL V VAAIABLES ARE USED IN THE CALCULATION OF DAILY DAVELOPMENT
C
C VONE   = IS THE DAYLENGTH COMPONENT
C VTWO   = IS THE MAXIMUM TEMPERATURE COMPONENT
C VTHREE= IS THE MINIMUM TEMPERATURE COMPONENT
C VFOUR  = VTHREE*VTWO WHICH ARE THE TEMPERATURE COMPONENTS.
C
```

```
C DEFINITIONS OF ARRAYS USED IN THE MAIN PROGRAM.
C
C A(I)    A(1)=COEF(1); A(2)=COEF(2); A(3)=COEF(3)
C B(I)    B(1)=COEF(4); B(2)=COEF(5); B(3)=COEF(6)
C C(I)    C(1)=COEF(7); C(2)=COEF(8)
C AC CONTAINS VALUES COMMON TO A(I) AN THE SUBROUTINE.
C         THE VALUES OBTAINED IN THE SUBROUTINE IN A(I)
C         ARE USED BY AC(I) LATER IN THE MAIN PROGRAM TO
C         GET NEW COEFFICIENTS.
C COEF  = CONTAIN THE STARTING SET OF COEFFICIENTS.
C DAY   = TEMPORARILY STORES DAYLENGTH VALUES FOR A GIVEN STN.
C IBEGIN= STORES THE BEGINNING DATE OF A GIVEN GROWTH STAGE
C         AT A GIVEN STATION.(VARIABLE KOUNT USED STN IDENTIFIER)
C IDCROP= IS THE VARIETY IDENTIFIER.
C         01=PORTAGE SOYBEANS
C         02= MCCALL SOYBEANS
C         03= MAPLE PRESTO SOYBEANS
C IDIOT = CONTAINS THE CORRESPONDING DATE FOR DAILY CLIMATIC
C         DATA.
C IEND  = STORES THE ENDING DATE OF A GIVEN GROWTH STAGE AT
C         A GIVEN STATION.
C IOUTXN= STORES THOSE DAILY MAXIMUM TEMPERATURES RELEVENT
C         FOR LATER CALCULATIONS
C IPHASE= INDICATES WHETHER WE´RE IN THE LIGHT PHASE=01
C         OR TEMPERATURE PHASE =02.
C ITEMP = STORES THOSE DAILY MINIMUM TEMPERATURES RELEVENT
C         FOR LATER CALCULATIONS.
C ITEMP1= TEMPORARILY STORES MINIMUM TEMPS FOR A GIVEN STN.
C ITEMP2= TEMPORARILY STORES MAXIMUM TEMPS FOR A GIVEN STN.
C LESTAG= STORES 12 GROWTH STAGE DATES FROM ONE STATION.
C MXDAYS IS THE FINAL KNTR2 VALUE FOR STATION (KOT), IE. THE
C         NUMBER OF DAYS BETWEEN IBEGIN AND IEND.
C NITER = INDICATES WHICH PHASE TO BE IN. 01=LIGHT; 02=TEMP
C         NITER(1)=02; NITER(2)=01......NITER(30)=01.
C OUTDAY= STORES THOSE DAILY DAYLENGTH VALUES RELEVENT FOR
C         DAILY CALCULATIONS
C SSX(I,J) = SUM OF THE CROSS PRODUCTS OF X(I) FOR ALL STATIONS
C         UNDER CONSIDERATION.
C         THESE VALUES ARE USED IN THE REGRESSION.
C SX(I)   = sum(X(I)) for all stations under consideration.
C         THESE VALUES ARE USED IN THE REGRESSION LATER.
C TITLE = ALPHA NUMERIC THAT PRINTS AN APPROPRIATE TITLE
C X VALUES ARE A CALCULATION OF A SEPARATE VALUES FOR THE
C         DIFFERENT SEGMENTS OF EQUATIONS 14 OR 15 (ROBERTSON 1968)
C         IF IN THE LIGHT PHASE:
C  X(1) = sum((V2+V3)*L/sum(V2+V3)  in Eqn. 15.
C  X(2) = sum((V2+V3)*L*L)/sum(V2+V3) in Eqn. 15.
C  X(3) = 1./sum(V2+V3)  left side of Eqn. 15.
C         IF PROGRAM IS IN THE TEMPERATURE PHASE THEN
C         X VALUES WOULD CORRESPOND TO SEGMENTS OF
C         EQUATION 14 (ROBERTSON 1968).
C
C
C   FILES USED IN THIS PROGRAM:
```

```
C
C          ITTERCONTROL: THIS FILE READS A TITLE, THE STARTING
C                        COEFFICIENTS, THE VARIETY (01-03), THE
C                        STAGE, THE NUMBER OF ITTERATIONS AND
C                        THE ORDER, THE NUMBER OF STATIONS, AND
C                        THE LAST DATE (274) SEPT 30.
C          MPVARSTARTDATES: (OR MCVAR..., OR PVAR...) THIS FILE
C                        CONTAINS THE STARTING DATES FOR EACH
C                        STAGE AT ALL STATIONS FOR THE VARIETY
C                        INDICATED IN THE FILE NAME.
C          ALLSTNDATA: THIS FILE CONTAINS ALL THE CLIMATIC DATA
C                        FOR ALL THE STATIONS FROM MAY 1 (122)
C                        TO SEPT 30 (274)
C
      DIMENSION TITLE(18),COEF(8),LESTAG(12),IDIOT(366),
     1ITEMP(100,366),DAY(366),IOUTXN(100,99),OUTDAY(100,99),IBEGIN(9),
     1IEND(9),MXDAYS(99)
      DIMENSION SX(11),SSX(11,11),AC(11),X(5),A(3),B(3),
     1C(2),IPHASE(2),NITER(30),ITEMP1(366),ITEMP2(366)
      EQUIVALENCE (A(1),COEF(1)),(B(1),COEF(4)),(C(1),COEF(7))
      DOUBLE PRECISION SX,SSX,AC
      COMMON SX,SSX,AC
      CASE=0.0
      IY=0
C
C READING IN THE CONTROL INFORMATION
C
 8888 READ(5,10001)TITLE,IPHASE,COEF,IDCROP,
     1IFIRST,LAST,MXITER,NITER,LASTYR,LASTDT,LIST
10001 FORMAT(10A4/8A4,2I4/4E10.4/4E10.4/4I2/15I2/15I2/2I4,I1)
10010 KOUNT=0
C
C READING IN THE GROWTH STAGE DATES
C
      READ(5,1)HEADNG
    1 FORMAT(A63)
10015 READ(5,10002)LECROP,LESTAG
10002 FORMAT(2X,I2,12I5)
      IF(LECROP-99)10020,10041,10041
10020 IF(LECROP-IDCROP)10015,10030,10015
10030 KOUNT=KOUNT+1
      IBEGIN(KOUNT)=LESTAG(IFIRST)
      IEND(KOUNT)=LESTAG(LAST)
      GO TO 10015
10041 DO 10080 J=1,99
       DO 10081 KOT=1,KOUNT
      ITEMP(KOT,J)=0
      IOUTXN(KOT,J)=0
10081 OUTDAY(KOT,J)=0.0
10080 CONTINUE
C
C READING IN THE CLIMATIC DATA
C
11040 KOT=1
```

```
      DO 10120 I=1,KOUNT
      KNTR1=0
10050 KNTR1=KNTR1+1
      KY=IY
      READ(5,10003) IY,ITEMP1(KNTR1),ITEMP2(KNTR1)
     1,DAY(KNTR1),IDIOT(KNTR1)
10003 FORMAT(1X,I2,7X,I3,2X,I3,4X,F6.2,2X,I4)
C
C SAVING AND STORING THE RELEVENT CLIMATIC DATA
C
      IF(IDIOT(KNTR1)-LASTDT)10050,10060,10060
10060 KNTR1=KNTR1-1
      IF(KOUNT)10130,10130,10070
10070 KNTR2=0
      ITEST1=IBEGIN(I)
      IF(ITEST1)10120,10120,10082
10082 ITEST2=IEND(I)
      IF(ITEST2)10120,10120,10087
10087 DO 10100 J=1,KNTR1
      IF(IDIOT(J)-ITEST1) 10100,10100,10090
10090 KNTR2=KNTR2+1
      ITEMP(KOT,KNTR2)=ITEMP1(J)
      IOUTXN(KOT,KNTR2)=ITEMP2(J)
      OUTDAY(KOT,KNTR2)=DAY(J)
      IF(IDIOT(J)-ITEST2)10100,10110,10110
10100 CONTINUE
      GO TO 10120
C
C WRITING  THE REVELENT CLIMATIC DATA FOR THE STATION
C
10110 CASE=CASE+1.0
      MXDAYS(KOT)=KNTR2
 9999 WRITE(6,10004)KNTR2,I,I,CASE,(J,ITEMP(KOT,J),
     1IOUTXN(KOT,J),OUTDAY(KOT,J),J=1,KNTR2)
C
C AVERAGING AND SUMMING OF CLIMATIC DATA. THESE VALUES ARE
C NOT USED IN ANY OTHER CALCULATIONS.
C
      A3=0.
      IA1=0
      IA2=0
      IZMN2=0
      IZMX2=0
      ZDY2=0.
      TDIV=KNTR2
      DO 6666 II=1,KNTR2
      IA1=IA1+ITEMP(KOT,II)
      IZMN2=IZMN2+ITEMP(KOT,II)**2
      IA2=IA2+IOUTXN(KOT,II)
      IZMX2=IZMX2+ IOUTXN(KOT,II)**2
      ZDY2=ZDY2+OUTDAY(KOT,II)**2
 6666 A3=A3+OUTDAY(KOT,II)
      A1=IA1
      A2=IA2
```

```
      ZDY=A3
      A1=A1/TDIV
      A2=A2/TDIV
      A3=A3/TDIV
      WRITE(6,7777)A1,A2,A3,IA1,IZMN2,IA2,IZMX2,ZDY,ZDY2
 7777 FORMAT(1X,3F8.2/14H SUM OF TMIN= ,
     1I6/22H SUM OF TMIN SQUARED= ,
     1I6/14H SUM OF TMAX= ,
     1I6/22H SUM OF TMAX SQUARED= ,
     1I6/19H SUM OF DAYLENGTH= ,
     1F6.2/27H SUM OF DAYLENGTH SQUARED= ,F10.2)
10004 FORMAT(I3,2I4,F6.2)
      KOT=KOT+1
10120 CONTINUE
10130 IF(KY-LASTYR)10010,10146,10010
C
C
C
10146 OPMAX=0.0
      OPMIN=0.0
      OPDAY=0.0
      AVGK=0.0
      COVAR=0.0
      ITTER=NITER(1)
      WRITE(6,10005) TITLE
10005 FORMAT(18A4)
      WRITE(6,10006)CASE
10006 FORMAT(17H NUMBER OF CASES ,F4.0)
      DO 10035 I=1,MXITER
      ITTER=NITER(I)
10035 WRITE(6,10007)I,IPHASE(ITTER)
10007 FORMAT(11H RUN NUMBER,I2,8H IS FOR ,I4)
C
C
C BEGINNING OF REGRESSION LOOP.
C ONE TIME THROUGH THIS LOOP IS ONE ITTERATION.
C
   20 DO 670 NOITER= 1,MXITER
      WRITE(6,4567)
4567  FORMAT(26H A,B,C AFTER STATEMENT  20)
      WRITE(6,2345)A,B,C
      ITTER=NITER(NOITER)
      WRITE(6,51)ITTER
   51 FORMAT(8H ITTER= ,I2)
C
C INITIALIZING OF VARIABLES FOR DO LOOP 670
C
   30 MXPLNT=CASE
      NOREG=MXPLNT
      CONTCV=MXPLNT
      KOUNT1=0
      KOUNT2=0
      KOUNT3=0
      KOUNT4=0
```

```
      KOUNT5=0
      KOUNT6=0
      KOUNT7=0
      DO 35 I=1,11
      SX(I)=0.0
      DO 36 J=1,11
   36 SSX(J,I)=0.0
   35 CONTINUE
      SUMKS=0.0
      SUMKSS=0.0
      GO TO 80
C
C     MULTI-BRANCH AS A CENTRAL CONTROL
C
   60 INDEX=INDEX+ITTER
   70 GO TO(460,460,460,460,490,491,610,592,620,625,650,
     1660),INDEX
C
C BEGINNING OF LOOP 430.
C THIS LOOP GOES THROUGH ONCE FOR EVERY STATION
C
   80 KOT=0
      DO 430 NOPLNT=1,MXPLNT
C
C INITIALIZING VARIABLES FOR LOOP 430
C
      KOT=KOT+1
      ACCUM1=0.0
      ACCUM2=0.0
      ACCUM3=0.0
      ACCUM4=0.0
      ACCUM5=0.0
      SUMK=0.0
      IMXDAY=MXDAYS(KOT)
C
C BEGINNING OF LOOP 300
C
C CALCULATION OF DAILY DEVELOPMENT WITH PRESENT SET OF COEFFICIENTS
C
      DO 300 NODAY=1,IMXDAY
      TEMPMN=ITEMP(KOT,NODAY)
      TEMPMX=IOUTXN(KOT,NODAY)
      DAM=OUTDAY(KOT,NODAY)
      IF(A(2)*(DAM-A(1)).GT.0.)GO TO 130
      VONE=0.
      KOUNT1=KOUNT1+1
      GO TO 150
  130 WORK=DAM-A(1)
      VONE=A(2)*WORK+A(3)*WORK*WORK
      IF(VONE)140,140,150
  140 VONE=0.0
      KOUNT2=KOUNT2+1
  150 WORK=TEMPMX-B(1)
      IF(WORK.GT.0.)GO TO 170
```

```
      VTWO=0.
      KOUNT3=KOUNT3+1
      GO TO 190
  170 VTWO=B(2)*WORK+B(3)*WORK*WORK
      IF(VTWO)180,180,190
  180 VTWO=0.0
      KOUNT4=KOUNT4+1
  190 WORK=TEMPMN-B(1)
      IF(WORK.GT.0.)GO TO 210
      VTHREE=0.
      KOUNT5=KOUNT5+1
      GO TO 230
  210 VTHREE=C(1)*WORK+C(2)*WORK*WORK
      IF(VTHREE) 220,220,230
  220 VTHREE=0.0
      KOUNT6=KOUNT6+1
  230 VFOUR=VTHREE+VTWO
      IF(VFOUR)235,235,237
  235 KOUNT7=KOUNT7+1
      VFOUR=0.0
  237 SUMK=SUMK+VONE*VFOUR
C
C CONTROL TO DESIGNATE LIGHT OR TEMPERATURE COMPUTATIONS
C THAT WILL BE USED LATER IN CALCULATIONS FOR REGRESSION.
C
  238 INDEX=ITTER
      GO TO(240,260),ITTER
C
C LIGHT PHASE COMPUTATION
C
  240 IF(VONE)300,300,250
  250 WORK=VFOUR
      ACCUM1=ACCUM1+WORK
      ACCUM2=ACCUM2+WORK*DAM
      ACCUM3=ACCUM3+WORK*DAM*DAM
      GO TO 300
C
C TEMPERATURE PHASE COMPUTATION
C
  260 IF(VFOUR)300,300,266
  266 IF(VTWO)295,295,270
  270 ACCUM2=ACCUM2+VONE*TEMPMX
      ACCUM3=ACCUM3+VONE*TEMPMX*TEMPMX
  295 IF(VTHREE)290,290,286
  286 ACCUM4=ACCUM4+VONE*TEMPMN
      ACCUM5=ACCUM5+VONE*TEMPMN*TEMPMN
  290 ACCUM1=ACCUM1+VONE
  300 CONTINUE
      WRITE(6,76)SUMK
   76 FORMAT(6H SUMK=,E11.4)
C
C END OF DAILY COMPUTING LOOP 300
C
      INDEX=2+ITTER
```

```
          GO TO (310,330),ITTER
C
C SEPERATE ACCUMULATIONS FOR REGRESSIN
C X(I) VALUES CORRESPOND TO THE CONSTANTS
C IN REGRESSION EQUATIONS..
C
C
C COMPUTATION FOR LIGHT PHASE
C
      310 IF(ACCUM1)370,370,320
      320 X(1)=ACCUM2/ACCUM1
          X(2)=ACCUM3/ACCUM1
          X(3)=1./ACCUM1
          KNOB=3
          GO TO 380
C
C COMPUTATION FOR TEMPERATURE PHASE
C
      330 IF(ACCUM1) 370,370,340
      340 X(1)=ACCUM2/ACCUM1
          X(2)=ACCUM3/ACCUM1
          X(3)=ACCUM4/ACCUM1
          X(4)=ACCUM5/ACCUM1
          X(5)=1./ACCUM1
      369 KNOB=5
          GO TO 380
      370 NOREG=NOREG-1
          GO TO 400
C
C SUMMING OF X(I)´S AND SUMMING OF PRODUCTS OF X(I)
C FOR REGRESSION
C
      380 DO 390 I=1,KNOB
          SX(I)=SX(I)+X(I)
          DO 390 J=1,I
      390 SSX(J,I)=SSX(J,I)+X(J)*X(I)
      400 IF(SUMK)410,410,420
      410 CONTCV=CONTCV-1.
          GO TO 430
      420 SUMKS=SUMKS+SUMK
          SUMKSS=SUMKSS+SUMK*SUMK
      430 CONTINUE
C
C END OF STATION LOOP 430
C
          WRITE(6,77)SUMK,SUMKS,SUMKSS
       77 FORMAT(6H SUMK=,E11.4,7H SUMKS=,E11.4,8H SUMKSS=,E11.4)
C
C
C REGRESSION ANALYSIS SECTION
C
C CHECK AND MODIFICATION (IF NECESSARY) OF SX(I) VALUES.
C
          ISET=1
```

```
      IF(SX(KNOB))431,460,431
  431 IF(SX(1))433,432,433
  432 ISET=ISET+1
  433 IF(ITTER-1)434,434,435
  434 GO TO (450,460),ISET
  435 IF(SX(3))436,436,437
  436 ISET=ISET+2
  437 GO TO (450,438,440,460),ISET
  438 DO 439 I=1,3
      SX(I)=SX(I+2)
      DO 439 J=I,3
  439 SSX(I,J)=SSX(I+2,J+2)
      GO TO 441
  440 SX(3)=SX(5)
      SSX(1,3)=SSX(1,5)
      SSX(2,3)=SSX(2,5)
      SSX(3,3)=SSX(5,5)
  441 KNOB=3
C
C CALLING OF REGRESSION SUBROUTINE
C
C SX(I) AND SSX(I,J) ARE COMMON TO MAIN PROGRAM AND
C REGRES SUBROUTINE AND THEREFORE DO NOT HAVE TO BE INCLUDED
C IN THE CALL STATEMENT.
C
  450 CALL REGRES(KNOB-1,NOREG)
C
C REGRESSION IS COMPLETED AND THE REGRESSION COEFFICIENTS
C ("P" OR "Q") ARE IN THE ARRAY AC(I) WHICH IS COMMON TO
C THE SUBROUTINE ARRAY A(I).
C
      WRITE(6,1234)
 1234 FORMAT(23H AC AFTER STATEMENT 450)
      WRITE(6,2345)AC
 2345 FORMAT(8E11.4)
C
C CHECK TO SEE  IS PROGRAM IS IN THE LIGHT OR TEMPERATURE PHASE
C
  480 INDEX=4
      GO TO 60
C
C IF PROGRAM IS IN LIGHT PHASE THEN AC(4) AND AC(5) MUST
C BE GIVEN THE VALUES OF AC(2) AND AC(3) VALUES SO THAT
C THE CALCULATION OF "A" OR "B" COEFFICIENTS CAN BE MADE
C IN THE SAME SECTION
C
  490 AC(5)=AC(3)
      AC(3)=0.0
      AC(4)=0.0
      GO TO 500
  491 GO TO (500,493,490),ISET
  493 AC(5)=AC(3)
      AC(4)=AC(2)
      AC(3)=AC(1)
```

```
      AC(2)=0.0
C
C CALCULATION OF "A" OR "B" COEFFICIENTS FROM "P" OR "Q" COEFS.
C
  500 AT=AC(1)+AC(3)
      WORK=AT*AT-(4.*AC(5)*(AC(2)+AC(4)))
C
C CHECK TO SEE IF WORK IS NEGATIVE. IF THIS IT IS THEN
C A CALCULATION OF "AO" OR "BO" CAN NOT BE MADE.
C THE PROGRAM THEN GOES TO STATEMENT 590.
C
      IF(WORK) 590,510,510
  510 SAT=2.*(AC(2)+AC(4))
      WORK=SQRT(WORK)
      ACCUM1=(-AT+WORK)/SAT
      ACCUM2=(-AT-WORK)/SAT
      GO TO (511,512),ITTER
  511 IF(A(3)*A(2)) 512,512,514
  512 IF(ACCUM1-ACCUM2) 530,530,520
  514 IF(ACCUM1-ACCUM2) 520,530,530
  520 ACCUM1=ACCUM2
  530 ACCUM2=AC(1)+(2.0*ACCUM1*AC(2))
      ACCUM3=AC(2)
      ACCUM4=AC(3)+(2.*ACCUM1*AC(4))
      ACCUM5=AC(4)
C
C CALCULATION OF OPTIMUM MAXIMUM  AND MINIMUM TEMPERATURES
C AND DAYLENGTHS.
C
      IF(AC(2)) 550,540,550
  540 OPTM1= +.9999E+50
      GO TO 560
  550 OPTM1=AC(1)/(AC(2)*2.)*(-1.)
  560 IF(AC(4)) 580,570,580
  570 OPTM2=+.9999E+50
      GO TO 640
  580 OPTM2=AC(3)/(AC(4)*2.)*(-1.)
      GO TO 640
C
C ADJUSTMENT OF SX AND SSX VALUES PRIOR TO GOING THROUGH
C ANOTHER REGRESSION USING THE SAME DATA.
C THIS SECTION IS USED ONLY IF "WORK" WAS NEGATIVE.
C
  590 SX(2)=SX(3)
      SSX(1,2)=SSX(1,3)
      SSX(2,2)=SSX(3,3)
      KNOB=1
      INDEX=6
      GO TO 60
  592 GO TO (600,610,610),ISET
  600 SX(3)=SX(5)
      SSX(3,3)=SSX(5,5)
      SSX(1,3)=SSX(1,5)
      SSX(2,3)=SSX(3,5)
```

```
      KNOB=2
C
C CALLING  THE REGRESSION SUBROUTINE
C
  610 CALL REGRES(KNOB,NOREG)
      WRITE(6,3456)
 3456 FORMAT(23H AC AFTER STATEMENT 610)
      WRITE(6,2345)AC
      INDEX=8
      GO TO 60
C
C CALCULATION OF "A " OR "B" COEFFICIENTS FOLLOWING REGRESSION
C
  620 AC(3)=AC(2)
      AC(2)=0.0
      GO TO 630
  625 GO TO (630,628,620),ISET
  628 AC(3)=AC(2)
      AC(2)=AC(1)
      AC(1)=0.0
  630 ACCUM1=-AC(3)/(AC(1)+AC(2))
      ACCUM2=AC(1)
      ACCUM3=0.0
      ACCUM4=AC(2)
      ACCUM5=0.0
      OPTM1=0.0
      OPTM2=0.0
  640 WRITE(6,11)IPHASE(ITTER),NOITER,KOUNT1,KOUNT2,KOUNT3,
     1KOUNT4,KOUNT5,KOUNT6,KOUNT7,NOREG,CONTCV
   11 FORMAT(27X,I4/11H  ITERATION ,I3,1X,8I5,F6.0/)
C
C CALCULATION OF COEFFICIENT OF VARIABILITY
C
      SAVGK=AVGK
      SCOVAR=COVAR
      AVGK=SUMKS/CONTCV
      WORK=SUMKSS/CONTCV
      COVAR=100.*SQRT (CONTCV*(WORK-AVGK*AVGK)/(CONTCV-1.))/AVGK
      INDEX=10
      GO TO 60
C
C REDEFINING OF LIGHT COEFFICIENTS
C
  650 ACCUM4=1.
      OPTM1=OPTM1+A(1)
      WRITE(6,7)B,C,A,OPDAY,SAVGK,SCOVAR,ACCUM1,ACCUM2,ACCUM3,
     1OPMT1,AVGK,COVAR
    7 FORMAT(5H MAX ,3E11.4,4H MIN,2E11.4//8H OLD LIT,3E11.4,
     11X,3E11.4/8H NEW LIT ,3E11.4,1X,3E11.4/ )
      A(1)=ACCUM1
      A(2)=ACCUM2
      A(3)=ACCUM3
      B(2)=B(2)*ACCUM4
      B(3)=B(3)*ACCUM4
```

```
      C(1)=C(1)*ACCUM4
      C(2)=C(2)*ACCUM4
      OPDAY=OPTM1
      GO TO 670
C
C REDEFINING OF TEMPERATURE COEFFICIENTS
C
  660 OPTM1=OPTM1+B(1)
      OPTM2=OPTM2+B(1)
      WRITE(6,8)A,B,OPMAX,ACCUM1,ACCUM2,ACCUM3,OPTM1,B(1),C,
     1OPMIN,SAVGK,SCOVAR,ACCUM1,ACCUM4,ACCUM5,OPTM2,AVGK,COVAR
    8 FORMAT(5H LIT ,3E11.4//8H OLD MAX,3E11.4,1X,E11.4/
     18H NEW MAX,3E11.4,1X,E11.4//8H OLD MIN, 3E11.4,1X,
     13E11.4/8H NEW MIN,3E11.4,1X,3E11.4/)
      B(1)=ACCUM1
      B(2)=ACCUM2
      B(3)=ACCUM3
      C(1)=ACCUM4
      C(2)=ACCUM5
      OPMAX=OPTM1
  670 OPMIN=OPTM2
C
C END OF ITTERATION LOOP 670
C
  460 STOP
      END
C
C
C  SUBROUTINE REGRES
C
C
      SUBROUTINE REGRES (NODVAR,NOCASE)
      DIMENSION SX(11),SSX(11,11),C(6),T(18,12),A(11)
      DOUBLE PRECISION SX,SSX,A,C,T,AN
      COMMON SX,SSX,A
      AN=NOCASE
      N=NODVAR+1
      ISHIFT=N*2
      MOVE=N+ISHIFT
      DO 10 I=1,MOVE
      DO 10 J=1,ISHIFT
   10 T(I,J)=0.0
      DO 20 I=1,N
      M=I+N
      T(I,M)=1.0
      DO 20 J=I,N
   20 T(I,J)=SSX(I,J)-SX(I)*SX(J)/AN
      M=N+1
      DO 40 L=1,N
      MOVE=NODVAR+L*2
      MAX=L+N
      DO 40 ISHIFT=L,MAX
      T(MOVE,ISHIFT)=T(L,ISHIFT)
      IF(L-1) 40,40,25
```

```
   25 MXDOWN=MOVE-2
      DO 30 ISTEP=M,MXDOWN,2
   30 T(MOVE,ISHIFT)=T(MOVE,ISHIFT)-T(ISTEP,ISHIFT)*T(ISTEP+1,L)
   40 T(MOVE+1,ISHIFT)=T(MOVE,ISHIFT)/T(MOVE,L)
      DO 50 I=1,N
      ISTEP=I+N
   50 C(I)=T(MOVE,ISTEP)*T(MOVE+1,2*N)
      A(N)=SX(N)
      DO 60 I=1,NODVAR
      A(I)=(-1.*C(I))/C(N)
   60 A(N)=A(N)-A(I)*SX(I)
      A(N)=A(N)*(1./AN)
      WRITE(6,91)A
   91 FORMAT(8H A=     ,3E11.4/)
      RETURN
      END
$ENTRY
```

Appendix C

DATES THAT EACH PHENOLOGICAL STAGE WAS REACHED FOR EACH VARIETY FOR ALL NINE STATION YEARS.

VARIETY	PLT	VE	VC	V1	R1	R2	R3	R4	R5	R6	R7	R8
WINNIPEG 1979												
PORTAGE	23/5	05/6	10/6	18/6	10/7	14/7	21/7	24/7	30/7	12/8	30/8	05/9
MCCALL	23/5	03/6	09/6	16/6	06/7	11/7	20/7	24/7	01/8	13/8	05/9	-
M.PRESTO	23/5	04/6	10/6	16/6	02/7	06/7	10/7	16/7	23/7	01/8	18/8	24/8
MORDEN 1979												
PORTAGE	28/5	12/6	12/6	21/6	13/7	18/7	26/7	02/8	10/8	21/8	04/9	12/9
MCCALL	28/5	11/6	12/6	19/6	09/7	16/7	25/7	03/8	11/8	24/8	11/9	-
M.PRESTO	28/5	11/6	12/6	19/6	07/7	10/7	16/7	25/7	31/7	10/8	25/8	02/9
WASKADA 1979												
PORTAGE	24/5	12/6	13/6	20/6	13/7	17/7	23/7	29/7	07/8	16/8	28/8	04/9
MCCALL	24/5	10/6	12/6	19/6	07/7	11/7	20/7	27/7	08/8	17/8	31/8	04/9
M.PRESTO	24/5	11/6	23/6	18/6	06/7	10/7	14/7	18/7	24/7	04/8	16/8	24/8
BRANDON 1979												
PORTAGE	06/6	17/6	18/6	26/6	21/7	26/7	01/8	06/8	14/8	24/8	06/9	12/9
MCCALL	06/6	17/6	17/6	26/6	19/7	23/7	29/7	04/8	12/8	24/8	10/9	18/9
M.PRESTO	06/6	17/6	17/6	25/6	13/7	17/7	21/7	25/7	30/7	10/8	24/8	01/9
DAUPHIN 1979												
PORTAGE	07/6	22/6	24/6	30/6	27/7	02/8	10/8	19/8	03/9	13/9	-	-
MCCALL	07/6	20/6	24/6	30/6	25/7	30/7	08/8	18/8	04/9	14/9	-	-
M.PRESTO	07/6	21/6	24/6	30/6	15/7	21/7	28/7	03/8	16/8	29/8	10/9	18/9
MORDEN 1980												
PORTAGE	09/5	27/5	27/5	01/6	25/6	30/6	05/7	11/7	23/7	04/8	18/8	28/8
MCCALL	09/5	21/5	25/5	01/6	22/6	28/6	04/7	12/7	25/7	04/8	25/8	01/9
M.PRESTO	09/5	26/5	27/5	31/5	21/6	26/6	29/6	05/7	12/7	24/7	05/8	12/8
BRANDON 1980												
PORTAGE	27/6	06/7	07/7	10/7	31/7	08/8	15/8	27/8	09/9	-	-	-
MCCALL	27/6	06/7	07/7	11/7	02/8	08/8	16/8	31/8	12/9	-	-	-
M.PRESTO	27/6	06/7	07/7	09/7	29/7	05/8	10/8	17/8	26/8	11/9	-	-
DAUPHIN 1ST DATE 1980												
PORTAGE	17/5	-	-	11/6	07/7	18/7	27/7	03/8	15/8	29/8	08/9	26/9
MCCALL	17/5	-	-	11/6	05/7	10/7	26/7	06/8	17/8	29/8	08/9	27/9
M.PRESTO	17/5	-	-	11/6	30/6	08/7	14/7	23/7	02/8	09/8	26/8	08/9
DAUPHIN 2ND DATE 1980												
PORTAGE	07/6	17/6	23/6	01/7	25/7	29/7	05/8	13/8	24/8	07/9	24/9	-
MCCALL	07/6	17/6	23/6	02/7	25/7	29/7	05/8	15/8	27/8	09/9	-	-
M.PRESTO	07/6	18/6	23/6	02/7	17/7	23/7	28/7	04/8	20/8	01/9	08/9	-

Appendix D

VOLUMETRIC WATER CONTENTS OF FIRST 20 CM AT THREE STATIONS IN 1980.

Station and Date	Volumetric water content (%) depth (cm) 0-5	5-10	10-15	15-20
Morden 1980				
May 15	3.3	26.0	23.5	28.9
May 30	16.8	22.6	27.1	27.0
June 12	7.2	27.6	28.5	33.9
June 26	13.1	25.6	29.5	30.0
July 11	19.4	25.0	24.7	28.3
July 23	20.7	27.0	27.3	27.9
Aug 8	24.8	23.8	24.1	23.2
Aug 22	30.8	31.0	33.5	31.1
Brandon 1980				
June 5	12.1	12.9	14.0	27.7
June 19	6.1	16.9	16.3	21.4
July 3	14.1	28.1	28.6	32.0
July 17	29.5	32.1	31.2	33.6
July 31	26.3	26.1	30.3	29.3
Aug 14	31.0	32.7	33.0	34.1
Aug 28	29.1	28.4	30.0	33.1
Dauphin 1980(2)				
June 5	33.2	34.0	48.7	47.2
June 20	23.4	41.2	54.0	52.9
July 4	43.2	57.6	55.8	56.2
July 24	40.8	48.7	50.9	49.1
Aug 7	41.0	48.6	48.4	47.7
Aug 21	41.4	41.2	46.7	47.4