THE UNIVERSITY OF MANITOBA

THE INFLUENCE OF PHYSICAL ENVIRONMENTAL FACTORS ON THE PRODUCTIVITY POTENTIAL OF FABABEANS.

by

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ABSTRACT.

Evaluation of the influence of soil physical and agroclimatic variables on fababean production indicates that accumulated soil and atmospheric heat, evapotranspiration and soil moisture supply are critical factors in determining seed and silage yields. Satisfactory yields are only obtained when the soil moisture supply in the upper portion of the profile is adequate and when the level of accumulated soil heat at 20 cm depth exceeds the atmospheric heat accumulation by approximately 100 units. Growth on the main stem ceases after the receipt of between 1000 and 1150 soil heat units, the total within these limits being dependent upon soil moisture supply in the upper portion of the soil profile. Fababean production in Manitoba should not be limited by environmental factors in areas recieving less than 1550 atmospheric heat units between May 1st and September 30th and possessing a soil water deficit on September 30th of less than 20 cm.

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I INTRODUCTION

In 1974 the Department of Soil Science participated in a multidisciplinary project which was initiated to review the agricultural potential of the high protein seed legume Vicia faba L.

The responsibility designated to this particular portion of the project was an examination of the influence of the physical environment on the growth performance of this crop. This involved field, growth chamber and laboratory studies in which an attempt was made to quantify the individual and combined effects of agroclimatic and soil physical variables on crop development and yield productivity.

When this analysis was complete it was hoped that the relationships developed would allow prediction of which climatic areas in the Province would be most suitable for large scale field production of fababean seed and silage.

II REVIEW OF PREVIOUS RESEARCH

Seasonal Supply of Moisture

An adequate soil moisture supply is a critical requirement for successful legume growth (Salter and Goode, 1967). The level that can be regarded as adequate is dependent upon the ability of a crop to extract water under the tension at which it is being held in the soil. This moisture is required to maintain sufficient cell turgor to allow plant processes such as photosynthesis to occur unimpeded and also to provide a root environment suitable for a high rate of nitrogen fixation by the nodulating bacteria (Kuo and Boersma, 1971). If an adequate moisture supply is not maintained throughout the growing season this will be reflected in reduced plant growth performance, particularly in the case of Vicia faba minor which is a crop very sensitive to drought because its ability to utilize soil moisture reserves is limited (Listowski et al., after Gliemmeroth, 1952).

Field experimental results of El Nadi (1970) on Vicia faba major indicate that grain yields may be doubled when the moisture supply in the top 15 cm of profile is maintained above average levels (ie. greater than 20% of water on a dry soil basis). This was compared to irrigating when visual symptoms of water stress were apparent in the crop (i.e. less than 15% of water on a dry soil basis).

Examination of the irrigation requirements of the horsebean by Gibali et al. (1968) have shown that a frequency of water application of twenty days results in a 25% yield increase over application every 60 days when the amount of water applied is sufficient to raise the level to field capacity plus 10%. This observation is supported by Listowski et al. (1966) who record a 103% increase in horsebean (Vicia faba minor) seed yield as the maximum soil water stress was increased from 30 to 70% of available moisture. This increase was also apparent in straw dry matter production for the same moisture treatments.

Jones (1963) using broad beans (Vicia faba major) has studied the influence of soil moisture in another fashion. He established a set level of water table at various depths in large pots. The response in seed yield showed that the 25 and 36 cm depth treatments yielded one third more than the 46 and 56 cm depth treatments. This reflects the initial check in growth experienced by the plants before they were able to obtain adequate root development at the deeper water table depths. This emphasizes the need for adequate moisture supply in the initial growth stages if good yields are to be obtained.

Mack et al. (1966) in an examination of pole bean productivity monitored the maximum soil moisture tension at 30 cm depth to determine the required frequency of irrigation to produce optimum yields. When the maximum tension imposed was reduced from 4.5 to 0.9 bars, yields increased by 63%. Kuo and Boersma (1971) report that in the case of three week old soybeans (Glycine Max. (L.) Merr.) as soil moisture tension was increased from 0.35 to 2.50 bars the rate of nitrogen fixation was reduced 41.5% with a corresponding 56% drop in dry matter production. Similarly, Burman and Bohmont (1961) using great northern beans, found that an increase in the maximum soil moisture tension from 0.5 to 1 bar results in a 42% decrease in seed yield.

If soil moisture conditions are inadequate for maximum crop growth performance and the supply of irrigation water is limited, then the growth stage at which the supplemental irrigation is applied may be critical in determining the magnitude of the increase in final dry matter or seed yields (Salter and Goode, 1967). Experimental results of El Nadi (1970) on Vicia faba major show that supplemental irrigation in the pod development to harvest growth stage resulted in a 29% yield increase over a check treatment. This compares with a 10% yield increase when the supplemental irrigation occurred in the emergence to pod development stage. This indicates a greater plant sensitivity of grain yield to soil moisture deficit in the later growth stages. However, maintenance of an adequate moisture supply throughout the entire growing season was clearly the most satisfactory treatment resulting in a 78% yield increase over the drier check treatment.

Salter (1963) examined the yield response of peas to additions of moisture at various growth stages and he considered that irrigation in the preflowering vegetative phase did not increase yields. When the supplemental irrigation was applied only in the flowering stage, seed yield was increased by 30% over the check treatment; similarly water addition only in the pod swelling stage increased yields by 20%. These results emphasize the greater yield response resulting from ensuring an adequate moisture supply in the reproductive growth phases. Salter and Goode (1967) have concluded from the work of Reisch (1952); Stolp (1957, 1960) and Brouwer (1949, 1959) that yields of broad and field beans were also favourably increased by supplemental irrigation during the moisture sensitive flowering stage and that irrigation at the later growth stages was beneficial. However, for <u>Vicia faba major</u>, Jones (1963) considered that the attainment of a high plant growth rate before flowering was essential if good seed yields were to be obtained. Also Maurer <u>et al.</u> (1969) found that there was no significant difference in the total dry matter production of snap beans when a moderate tension treatment (0.5 bar) was imposed in either the seeding to flowering stage or the flowering to harvest stage.

Atmospheric Temperature

It is clear that all crop types do not respond to varying environmental conditions in a similar fashion. Yet near optimal yields can generally be obtained under a range of air temperature regimes given that other factors involved are non-limiting. The identification of the boundaries and extent of this range and the interaction of temperature with other environmental variables for particular crops is as yet only poorly understood. Hodgson (1967) has shown that for Vicia faba equina relative growth rates are positively correlated with light and temperature and are very low (less than 0.06 gm/gm per day) when mean weekly air temperature iss less than 9 C. Maximum relative growth rates occurred at the highest mean temperatures experienced in the study (14-16 C). He concluded that horsebeans are less sensitive to seasonal fluctuations in environmental conditions than are sunflowers.

Evans (1957) considered variety to be a critical variable in the response of Vicia faba major to temperature conditions. For fast growing European spring beans maximum growth rates occurred from 23 to 30 C and for the slower growing European winter beans 20 to 26 C was optimal. However at the highest temperatures most varieties were only able to sustain high growth rates for a short period of time and a heavy yield of seed could equally well be obtained at 10 C over seven months as at 23 C over four months. He claimed that these results show that it is not the effect of high temperatures per se that causes bean growth to cease under hot dry field conditions and that Vicia faba major is less adversely effected by high temperatures than peas.

In the case of peas Fletcher et al.(1966) consider that a seasonal average maximum air temperature of 20-21 C represents an optimum level. Nonnecke et al.(1971) claim that an increase in day - night temperature regime from 17/7 to 27/17 C may result in a 70% decrease in seed yield. Stanfield et al.(1966) consider that the optimal temperature range for peas shifts with stage of plant maturity. This is represented by a change from an optimum of 21/16 C at the sixth node stage to 16/10 C at maturity.

Listowski et al.(1966) examined the influence of night temperature regime on the seed yield of Vicia faba minor and concluded that high night temperatures (mean 20 C) resulted in a reduction in yield of 18% compared to a mean night temperature of 11 C. However the influence of night temperature was not considered to be significant compared to soil moisture treatments which recorded a yield increase of 103% when the soil water deficit was lowered from 70 to 30% of available moisture. Evans(1957) supports the conclusion that lower night temperatures are favourable for the productivity of Vicia faba. Peters et al.(1971) report that in the case of soybeans (Glycine Max. L. Merr.) a reduction in the average night temperature from 29.4 to 18.3 C results in a 20% reduction in yield. However, Fattah and Wort (1970) record a 35% increase in the fresh pod weight of bush beans (Phaseolus vulgaris L.) when night temperatures were raised from 21 to 26 C.

C.E.Moore (1974, Personal Communication) suggests that fababeans will tolerate a warm climate up to certain levels (2700 corn heat units) and above this level yield return will be unsatisfactory (the **highest** corn heat unit accumulation in Manitoba is 2500 units). He considers that extremely high temperatures (greater than 32 C) will cause almost complete flower abortion and cessation of pod growth; and satisfactory reproductive development is only likely to occur below 30 C.

Soil Temperature

The productivity of a plant is affected by the development of its root system. This in turn is strongly influenced by the environmental conditions to which it is exposed, of which a major component is soil temperature (Sartain and Nelson, 1970). In the case of innoculated legumes the effect of soil temperature is of added importance as this is a controlling factor in the productivity of the nitrogen fixing root nodule bacteria, which are in general the principal source of nitrogen to the growing crop.

Kuo and Boersma (1971) in a laboratory study using three week old soybeans (Glycine Max. (L.) Merr.) indicated that as root temperatures increased from 15.6 to 37.8 C plant dry weight, net photosynthesis and nitrogen fixation rate initially increased slowly and then rapidly to reach optimum values around a temperature of 27 C. This was followed by decreasing values as temperatures increased further. A positive deviation from the optimal temperature of 27 C was shown to result in a reduction in nitrogen fixation rate comparable to that caused by an increase in soil moisture tension from 0.70-1.50 bars.

Mack and Ivarson (1972) in a field experiment using soybeans (Glycine Max.) concluded that yield was linearly related to increases in soil temperature and heat accumulation. Experimental results indicated a 43.4% increase in yield when the accumulated soil heat at 20 cm depth was raised from a total of 859 to 1822 day degree units above 5 C. (i.e. The number of degrees C per day by which the mean soil temperature at 20 cm exceeds a base temperature of 5 C, the total being accumulated over the growing season). There was also a matching decrease in yield of 82.4% when the heat accumulation was lowered to 408 units. These values correspond to mean daily soil temperatures of 11.2, 17.7 and 31.2 C and this represents an increase in yield on the warmer soil of 0.54 q/ha per degree C.

The experimental results of Sartain and Nelson (1970) on the soybean concur with previous workers in suggesting that optimum soil temperature values are near 28 C. They also consider that dry matter productivity is satisfactory over the 20-35 C range but that above this value a rapid deterioration in growth performance takes place.

Mack (1973) has shown for field peas (Pisum sativum L.) that considerably higher seed yields were obtained at a mean soil temperature of 10.4 C compared to higher temperatures of 18.5 and 29.2 C. However, maximum vine weights were recorded at the intermediate soil temperature 18.5 C. These values correspond to soil heat accumulations at 20 cm depth of 334, 840 and 1500 units.

Mack and Fallen (1974) in a study on white beans report that a considerable increase in yield occurs when the accumulated level of soil heat at 20 cm depth is raised from 602 to 1004 units (19.7 and 29.7 C temperature treatments), representing a 0.71 q/ha change in yield per degree C from the seasonal mean temperature 19.7 C. This clearly shows that white beans are closely related to soybeans in their soil temperature requirements but field peas require a radically different environment for maximum productivity.

Conclusions

The review of previous research shows that the response of individual seed legume crops to environmental conditions is highly varied. However it is apparent that even moderate deficits in available soil moisture result in reduced crop yields. Vicia faba appears to be relatively sensitive to soil moisture status throughout the growing season particularly in the reproductive growth phase.

It is clear that there will be a significant interaction in the effects of soil moisture, soil temperature and atmospheric temperature; but for non-limiting soil moisture conditions the optimum atmospheric temperature range for Vicia faba minor appears to be between that of peas and soybeans. High day and night temperatures are likely to cause yield reduction and low temperatures will probably reduce the crop growth rate. The effect of soil temperature variation on seed yield is not presently known for this crop.

III MATERIALS AND METHODS

Field Investigations

The locations of the experimental plots were specifically chosen in order to embrace the widest possible range of climatic conditions in Southern Manitoba. This was determined with reference to maps prepared by Shaykewich(1974). In particular the soil water deficit on September 30th map and the degree days above 5 C May 1st - September 30th map were utilized to choose plots with as large a variation in plant available soil moisture and air temperature conditions as possible. The sites chosen were Altona, Seven Sisters and Pilot mound; site descriptions are displayed in Tables 1 and 2.

Seeding dates were 4 - 5 weeks later than is recommended; the delay being caused by May rains and the need to share equipment time. The plots were strips (40 m x 5 m) located adjacent to fababean fertilizer trials which helped to reduce any bias in the data analysis from climatic "edge effects". Seeding rates (200 kg/ha) were greater than recommended and commercial innoculum (Nitragin (faba bean) Q culture Lot No. X27.)[1] was applied at a rate of 418 gm per 100 kg of seed. Convential seeding equipment was used. Adequate weed control was obtained by the use of Treflan

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[1] Supplier - Nitragin Co., Milwaukee, Wisconsin 53209, USA.

at the recommended rate as a pre-emergence herbicide for control of wild oats. Broadleaved weeds were removed by weekly handweeding of all plots.

Triple super phosphate was applied at a rate of 15 kg of P per hectare to ensure adequate availability of phosphorus to the crop. Adequate to good emergence was achieved at all sites with very few gaps in the plant stand. The plant densities (means of 15 random metre quadrats) were: Altona 56 plants/sq.m, Pilot Mound 66 plants/sq.m and Seven Sisters 44 plants/sq.m.

Environmental Parameters Recorded. Rainfall and daily maximum and minimum air temperatures were recorded from seeding to harvest either on site or in weather stations within a two mile radius of the plot. Weekly potential evapotranspiration values (cm) were calculated from this data using the shortened Baier and Robertson (1965) formula:

$$PE = (-87.03 + 0.928 Tmax + 0.933 Range + 0.486 Qo) \times 0.00864$$

where Tmax = Daily maximum air temperature

Range = Daily maximum - daily minimum air temperature

Qo = Solar energy falling on a horizontal surface at the top of the atmosphere in cal/sq.cm during one day.

Soil temperatures were measured weekly with a set of thermocouples at the following depths: 2.5,5,10,20,50,100 and 150 cm. From this data soil temperature heat units at 20 cm were calculated using 5 C as a base temperature. Soil moisture was measured weekly at 15 cm depth intervals to 135 cm with a neutron probe[2] at a voltage setting of 1175 v. Similar soil moisture measurements were also performed in a nearby barley fertilizer trial. 'Field capacities' were measured in the laboratory using initially air dried soil in small plastic cylinders. The top half of the soil column was saturated and after allowing 24 hours for moisture redistribution the water percentage of the wet portion of the soil column was determined on an oven dry soil basis. Wilting points were estimated from fifteen bar water contents measured with a pressure membrane apparatus. These measurements coupled with rainfall and soil moisture data allowed calculation of a weekly record of available soil moisture levels for each 15 cm increment of soil profile. This was also performed in nearby barley fertilizer trials and at Seven Sisters the soil moisture levels under fallow conditions were also recorded.

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[2] Model 5810 + 5920. Nuclear Chicago Co. Austin, Texas 78757, USA.

Crop Productivity Assessment. Growth performance of the crop was assessed from 20 particular plants randomly selected at emergence, from which mean weekly measurements of stem heights, node number and numbers of flowers and pods were recorded. Relative stem growth rate was calculated from this data.

Total dry matter production was assessed from weekly random harvests of 20 plants which were oven dried for 4 days at 65 C and then weighed to provide an estimate of mean plant weight. This was then converted to dry matter production on an area basis by multiplication by the appropriate stand density factor. Relative growth rates in q/ha.wk were calculated from this data. At harvest time, trial seed samples were taken in order to determine when yield reached a maximum and this occurred 14-15 weeks after seeding. The final harvest consisted of hand cutting 32 randomly chosen replicates of 25 plants each. Pods were removed by hand and allowed to air dry in the laboratory for ten days to two weeks. Shelling was performed by hand and the seed was oven dried at 65 C until constant weight was obtained. This enabled calculation of a mean per plant yield which was then multiplied by the plant density factor to give an estimated yield on an area basis in q/ha. Grain protein contents were assessed by Kjeldahl total nitrogen values multiplied by 6.25. Grain moisture contents were determined after oven drying at 70 C till constant weight was obtained.

Growth Chamber Studies

Soil moisture experiments. The first experiment was conducted using surface horizons of Almasippi sand and Red River clay. An equivalent of four kg of oven dry soil, seived to a maximum aggregate size of 4 mm, was placed in plastic pots; twenty pots of each soil were used. The fertility status of the soils used is displayed in Table 3. The Almasippi sand was treated with 20 ppm S applied as K_2SO_4 and the Red River clay recieved 20 ppm of P applied as KH_2PO_4 Six fababeans (variety Ackerperle) were innoculated with "Legume-aid"[3] and planted in each pot and after emergence the plants were thinned to three per pot. 'Field capacity' values were determined as previously discussed. Wilting percentages were estimated from 15 atmosphere percentages using polyethylene glycol 6000 as described by Williams and Shaykewich (1969).

Five moisture treatments were imposed with four replications for each soil, the first three treatments were 25, 50 and 75% maximum available water deficit and the

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3. Supplier - Ag.Labs.Inc., 1445 Chesapeake Av., Columbus, Ohio 43212, USA.

fourth and fifth treatments were the same as the first and second until flowering when the maximum available water deficit was reduced to 75%. Temperature controls on the growth chamber were 15/10 C day and night regime and the relative humidity regime was 45/85%. Lighting controls were set to provide a 16 hour day in which intensity of illumination increased to a maximum midway through the photoperiod and then decreased in order to simulate natural variations in sunlight as experienced in the field.

The second experiment was almost identical to the first experiment except that a new commercial innoculum was used: Nitragin (faba bean) Q culture Lot No. X27. The atmospheric temperature regime was also changed to 20/15 degrees C. and the number of plants per pot were reduced to two.

In the third and fourth experiments the soils used were sampled from the field experimental plots, the seed variety was changed to Diana to complement the field experiments. Fifteen pots of soil from both the Altona and Seven Sisters sites were used but there was only sufficient space for ten from the Pilot mound site. The moisture treatments employed were 33, 66 and 100% maximum available water deficit; except for the soil from the Pilot Mound site which did not include a 66% maximum available water deficit treatment. Otherwise conditions were identical to the second experiment.

Ambient temperature experiments. Enough Nitragin innoculated seed (Diana) was planted at weekly intervals for six weeks to ensure emergence of 30 seedlings per week. The growth chamber temperature setting was 20/15 C day and night regime, and soil moisture was maintained at field capacity. One week after seeding the seedlings were transplanted into pots of soil from the Seven Sisters site, three plants per pot. These were grown in the growth chamber for a further week and then placed in another growth chamber set at a constant 10 C. After allowing two days for temperature equilibration 15 of the plants (five pots) were harvested to determine dry weight. The remainder of the plants were grown for a further 5 days and then harvested to determine the increase in dry weight. Soil moisture was maintained close to field capacity throughout the experiment. This experiment was repeated exposing the plants in the second growth chamber to temperatures of 5, 15, 20, 25 and 30 C. Care was taken to ensure that all plants were at a similar stage of development before transfer into the second growth chamber. Any samples that did not meet this requirement were rejected and a substitute pot was utilized.

IV RESULTS AND STATISTICAL ANALYSIS

Field Experiment

1. Crop Growth Parameters

a). Dry Matter Production: A gross variation in growth rate, character and performance is evident in Table 4. Analysis of the curves of accumulated dry matter production per week (Figure 1) indicates that during pod filling at week 10 the productivity at Pilot Mound was twice as great as that at Altona and two-thirds greater than that at Seven Sisters. Production then ceased at Pilot Mound, it increased to a slightly greater total at Altona and at Seven Sisters it continued unabated up to week 14 when plant growth was curtailed by severe frost.

b). Seed quality and yields: There was a large variation within the replicates at each site, however the large number of replicates taken (32) ensured an accurate representation of the crop performance at each site. Results are displayed in Tables 5 and 6 and can best be described as average to poor compared to previous years. Two way analysis of variance indicated that location was a significant factor in yield determination: F = 58.2, DF. 31 and 2. However Duncan's multiple range test failed to differentiate at the 95% confidence level between yields at Seven Sisters and Pilot Mound; though both were significantly greater than at

Altona.

c). Stem and Nodal Development: In Table 7. it can be seen that up to week 10 similarity exists between Pilot Mound and Seven Sisters for these parameters. However after this time growth on the main stem and node production ceased at Pilot Mound whereas it continued at Seven Sisters almost until harvest; indicating a greater degree of indeterminance in growth habit at this site. At Altona node development on the main stem ceased at least two weeks earlier than at Pilot Mound and therefore six weeks earlier than at Seven Sisters.

2. Climatic Parameters.

Rainfall was poorly distributed throughout the growing season, Pilot Mound only receiving 3.5 cm in the first 10 weeks of growth, June and July being particularly dry at all sites (Table 8). Altona appears to have been warmer over the growing season, particularly in the latter half, than either Seven Sisters or Pilot Mound. This was reflected in greater heat unit accumulation, potential evaporation and mean weekly maximum and minimum temperatures. Seven Sisters was the only site affected by frost near harvest.

3. Soil Physical Parameters.

As rainfall was in short supply in the first 9-10 weeks of the growing season, reserves of available moisture in the soil proved to be a critical variable in determining crop growth performance (Table 9). At Pilot Mound available moisture supply in the top half of the profile was greater than at the other sites in the first half of the growing season, but considerably lower in the latter half. Moisture withdrawl in the fababean plot was fairly similar to that of the barley. This can be seen in Figures 2, 3 and 4.

Weekly soil temperature values at 20 cm were selected as being the most representative of root environmental conditions and also provide a temperature record from which short term oscillations are dampened indicating more clearly the real trend in changing temperature conditions (Table 10). Altona appears to have experienced overall warmer temperatures than either of the other two sites.

4. Data Analysis

Regression techniques were employed to analyze the amount of variation in plant growth parameters (dependent variables) explained by a series of environmental parameters (independent variables). The dependent variables considered are listed below:

PRGR = Per plant relative growth rate (gm/wk).
RGRQ = Crop relative growth rate (q/ha.wk).
PDWT = Per plant dry weight (gm).

TDWT = Accumulated crop dry matter production (q/ha).

NNOD = Number of differentiated nodes.

STHT = Stem height (cm).

SGRD = Stem growth rate (cm/day).

The independent variables considered were:

RAIN = Total weekly rainfall (cm).

MAXC = Mean weekly maximum temperature (C).

MINC = Mean weekly minimum temperature (C).

COIL = Weekly soil temperature at 20 cm (C).

STHU = Weekly soil temperature heat unit receipt at 20 cm depth, i.e. (T - 5.0) x 7.

ATHU = Weekly air temperature heat unit receipt.

ASTH = Accumulated soil metric heat units at 20 cm depth.

AATH = Accumulated air temperature metric heat units.

AVHF = Available soil moisture (cm) to 105 cm depth.

AVFF = Available soil moisture (cm) to 45 cm depth.

AVTH = Available soil moisture (cm) to 30 cm depth.

EVAP = Mean weekly potential evapotranspiration (cm).

CSSI = Evaporative demand stress i.e. weekly moisture consumption to 60 cm - weekly potential evapotranspiration (cm).

AESS = Soil moisture deficit stress to 60 cm depth i.e. available soil moisture to 60 cm - weekly potential evapotranspiration (cm).

AEST = Soil moisture deficit stress to 30 cm depth i.e. available soil moisture to 30 cm - weekly potential evapotranspiration (cm).

Initial linear regressions on the data as a whole (weeks 2-14) and considering only the values for weeks 5-11 led to the elimination of insignificant independent variables. The remainder were then reanalysed with multiple non-linear regression which incorporates quadratic and interaction variables in the data processing. In most cases highly significant relationships were established from the analysis between all plant development variables and environmental factors. Notable exceptions were PRGR and RGRQ which were both associated with low correlation coefficients indicating that they possessed little variation in common with the independent variables tested.

The equations listed below were generated using the week 2-14 data set; any relationships considered to be statistically not significant are not shown.

1). $\mathrm{PDWT} = -13.2 - 0.1081(\mathrm{AATH}) + 0.7136(\mathrm{AVHF}) + 0.1331(\mathrm{ASTH}) + 0.8983(\mathrm{EVAP})(\mathrm{EVAP}) + 0.07186(\mathrm{AVHF})(\mathrm{AVHF}) - 0.00001126(\mathrm{ASTH})(\mathrm{ASTH}) - 0.5975(\mathrm{EVAP})(\mathrm{AVHF})$.

$R^2 = 0.96$, S.E. = 1.49

2). $\mathrm{TDWT} = 43.36 + 0.2525(\mathrm{ASTH}) - 0.2312(\mathrm{AATH}) + 1.015(\mathrm{AVFF})(\mathrm{AVFF}) - 4.297(\mathrm{EVAP})(\mathrm{AVFF})$.

$R^2 = 0.93$, S.E. = 8.72

3). $\mathrm{NNOD} = 4.060 + 3.871(\mathrm{AVFF}) + 0.03277(\mathrm{ASTH}) - 0.0001147(\mathrm{ASTH})(\mathrm{ASTH}) - 0.04845(\mathrm{AVHF})(\mathrm{AVHF}) - 1.598(\mathrm{EVAP})(\mathrm{AVFF}) + 0.2441(\mathrm{EVAP})(\mathrm{AVHF})$.

$R^2 = 0.98$, S.E. = 1.27

4). $\mathrm{STHT} = 10.34 + 0.3054(\mathrm{ASTH}) - 0.1599(\mathrm{AATH}) - 0.00008165(\mathrm{ASTH})(\mathrm{ASTH}) + 0.374(\mathrm{AVHF})(\mathrm{AVFF}) - 0.3547(\mathrm{EVAP})(\mathrm{AVHF}) - 2.514(\mathrm{EVAP})(\mathrm{AVFF})$.

$R^2 = 0.98$, S.E. = 4.99

5). $\mathrm{SGRD} = -0.4022 + 0.003636(\mathrm{MAXC})(\mathrm{COIL}) - 0.002230(\mathrm{AVHF})(\mathrm{COIL})$.

$R^2 = 0.53$, S.E. = 0.51

The equations listed below were generated using the week 5-11 data set; insignificant relationships were omitted.

6). $\mathrm{PDWT} = 10.67 + 2.292(\mathrm{AVFF}) - 0.04486(\mathrm{AATH}) + 0.04445(\mathrm{ASTH}) - 1.246(\mathrm{AVFF})(\mathrm{EVAP})$.

$R^2 = 0.91$, S.E. = 1.47

7). TDWT = 44.33 +13.96(EVAP) +6.401(AVFF)(AVFF)
-12.27(EVAP)(AVFF).
$R^2 = 0.89$, S.E. = 8.6

8). NNOD = -14.17 + 0.1297(ASTH) - 0.05962(AATH)
-0.00003434(ASTH)(ASTH).
$R^2 = 0.95$, S.E. = 1.22

9). STHT = -85.34 +0.3102(ASTH) -0.000167(AATH)(AATH).
$R^2 = 0.91$, S.E. = 6.2

10). SGRD = -4.039 +0.01594(ASTH) - 0.00001182
(ASTH)(ASTH) +0.1429(EVAP)(AVTH).
$R^2 = 0.81$, S.E. = 0.36

Growth Chamber Experiments

Results are displayed in Tables 11, 12, 13 and 14. In Table 11 results are given for the treatments involving the Red River Clay but it is clear that nodulation failed to take place negating this half of experiment 1. No results are given for experiment 2 which was terminated at week 5 when the coolant fluid(water) was cut off at the mains in the growth chamber room without prior notice and all plants were killed by overheating. Similarly only limited results are given for experiment 3 which was also prematurely terminated at week 8 by a mechanical breakdown of the growth chamber temperature control which again killed the plants by overheating.

Considerable difficulty was also experienced in providing an environment suitable for adequate seed formation. Under constant temperature and humidity conditions the plant's growth habit appeared to be largely indeterminate and true seed maturity was never reached in the experiments. This situation was intensified by the breakdown of meaningful soil moisture treatments. After about nine weeks the plants became so large that the entire available moisture supply was often consumed in one day. This reflects a serious weakness in performing soil moisture experiments under pot conditions.

The unsatisfactory nature of the first four experiments was not experienced when the ambient temperature experiment was performed. The results of experiment 5 are therefore of greater validity. They indicated that maximum dry matter production over a fixed time period was experienced in the 15 and 20 C treatments. At higher and lower temperatures productivity was considerably reduced (Table 14 and Figure 5).

V DISCUSSION

Introduction

The influences of the physical environment on crop growth performance are complex and highly interdependent. Legume productivity is particularly sensitive to variations in temperature and moisture factors owing to a dependence on symbiotic nitrogen fixation. In this study an attempt is made to investigate these interelationships, to determine the relative importance of certain physical environmental variables and to assess the magnitude of their individual and combined effects on the productivity of the fababean. The culmination of this analysis is a consideration of the diversity in physical environment experienced by the various regions of the province and a recommendation as to which of these regions would be satisfactory for good fababean seed and silage production.

In the 1974 crop year fababean growth character and productivity was determined by the combined influences of temperature, evaporation and soil moisture. Seed yields and dry matter production were reduced due to stressed growth conditions imposed by inadequate soil moisture reserves and high levels of potential evapotranspiration during the vegetative, flowering and pod development growth stages. Atmospheric and soil temperature interelationships, in conjunction with soil moisture availability in the upper portion of the soil profile were responsible, for determining the rate of stem development and the date on which upward growth on the main stem ceased.

Soil Moisture and Evapotranspiration Effects

On consideration of the regression equations listed in Chapter four one conclusion immediately apparent is that soil moisture and evapotranspiration are responsible for explaining a large proportion of the variance recorded in the plant growth parameters. This is not an unexpected conclusion from data generated in a growth year in which precipitation was much reduced in the mid - summer months. It supports the experimental results of Listowski *et al.* (1966) and the opinions of Salter and Goode (1967) who stress the importance of soil moisture in the development of legume crops such as *Vicia faba* and *Pisum sativum*.

The magnitude of the effect of soil moisture on plant growth can be observed in Table 15 which shows that Equation 1 predicts an increase in plant dry weight of between 20 and 25% as available soil moisture supply is increased from 6-14 cm. The assumption made in this particular case is that soil temperature conditions are favourable (e.g. ASTH-AATH=100) and that potential evapotranspiration is constant. Clearly if this latter factor is allowed to increase, which is extremely likely under hot dry conditions, then the effects of moisture supply would become of still greater importance. The mechanisms by which plant growth is reduced may only reasonably be discussed in a simplified fashion in this study but it is clear that two major physiological conditions are involved. Firstly there will be a reduction in plant cell turgor pressure as the water potential in the zone surrounding the roots is decreased to such an extent that the plant is no longer able to extract water at a sufficient rate. This may result in a temporary closure of the stomatal openings and a consequent reduction in photsynthesis and transfer of nutrients within the plant and transfer of carbohydrates to the nodulating bacteria. Secondly a reduction in the water potential in the area inhabited by the Rhizobia will result in a decrease in nitrogen fixation (Kuo and Boersma, 1971).

Qualitative evidence for the effects of soil moisture on plant development was observed at Altona and Seven Sisters; where during the vegetative and flowering phases of development, temporary wilting of the crop occurred during the early afternoon period of highest potential evapotranspiration. The results of growth chamber Experiment 4 show a supporting trend to the previous conclusions with plant dry weight being increased by between 33 and 100% by decreasing the level of maximum available soil water deficit experienced (Table 13).

It has been suggested by several authors (Jones, 1963; Salter and Goode, 1967; and El Nadi, 1970) that <u>Vicia faba</u> is a crop which is subject to an enhanced sensitivity to moisture stress during particular growth stages. The results of Growth Chamber Experiment 1 do not display this effect (Table 11). However the field experiments provide evidence to indicate that this suggestion is valid. At Pilot Mound water supply was adequate until after pod set had occurred and though the resultant seed yields were best at this site, protein content was reduced. This contrasts with Altona where soil moisture appeared to be a limiting factor to growth during the vegetative, flowering and early pod set stages. Ample rainfall in later weeks was unable to compensate for this retardation in development. At Seven Sisters plant available moisture was in short supply during the vegetative phase but during the flowering stage, though rainfall receipt was not great, it was at least well distributed in time and the plants were under less stress than at Altona. As a result seed yield at Seven Sisters was comparable to that at Pilot Mound and protein content was considerably higher, possibly due to either ample rainfall and lower temperatures during the pod filling stage or the failure of the seed to reach full maturity due to frost.

These observations would seem to support the views of Salter and Goode (1967) that for *Vicia faba* the flowering/pod setting stages are particularly sensitive to moisture stress. Furthermore it would seem that low soil moisture supply in the pod filling stages of growth may inhibit protein development in the seed by depriving the plant of its symbiotic nitrogen supply. The conclusions of Jones(1963) would also appear to be valid but for dry matter production rather than seed yield. Since at Seven Sisters relative growth rate in the vegetative phase (Table 4) was lower than at Pilot Mound and had Seven Sisters attained comparable values, dry matter production could well have approached 13-15 t/ha.

The effect of soil moisture supply on dry matter production can also be observed in Table 16 which shows a theoretical evaluation of equation 10 in which evapotranspiration is held constant. These results clearly show that when 1000 soil temperature heat units have accumulated, growth on the main stem will cease when water supply in the top 30 cm of profile is low. If water supply is high growth will continue until 125-150 additional heat units have been accumulated and this results in a further 1-2 weeks growth represented by an increase of 1-3 t/ha of dry matter.

If Equation 3 is treated in a similar manner, assuming a mean value for evaporation and total water supply to 105 cm depth in the profile to be constant (AVPF), the results generated (Table 17) show that a decrease in the available moisture supply in the upper half of the profile will lead to a considerable decrease in the number of nodes differentiated on the main stem. This implies that under dry conditions leaf numbers and therefore total leaf area will be lower reducing the plant's photosynthetic potential; also the active growth period of the main stem will be shorter consequently depressing yields of dry matter.

The apparent significance of the observations of this section on the production of good fababean crops in Manitoba is profound. A considerable portion of the province is included in an area which possesses a soil moisture deficit on September the 30th of greater than 20 cm. This is displayed in Figure 6 which has been derived from data presented by Shaykewich (1974). This area would appear to represent conditions that are too dry for adequate seed or silage production. The effect of dry conditions is further intensified by the likelihood of receiving only limited precipitation in July when the crop is in the moisture sensitive flowering stage. Only areas in which the upper portion of the soil profile is maintained at reasonable levels of available moisture throughout the growing season can be expected to produce good yields of high protein seed or silage. This condition would probably be experienced in areas where the soil moisture deficit is less than 15 cm and this includes only a small portion of the agricultural zone of the Province (Figure 6).

Atmospheric and Soil Temperature

Examination of Equations 1-10 indicates that the critical involvement of soil moisture in fababean productivity is matched in importance by the interaction between environmental temperature variables. It is clear that the effects of temperature and moisture are to a substantial degree complementary through the action of evapotranspiration. However the independent influence of heat on plant productivity and development may also be considerable.

It would appear from the results generated from Equations 1 and 9 which can be observed in Tables 15 and 18 that crop productivity is dependent upon a favourable heat balance between the soil and atmosphere. Good growth only occurs when the heat accumulation of the soil is significantly greater than that accumulated in the atmosphere (i.e.ASTH-AATH=100). If this balance is not held, stressed growth conditions appear to prevail. This is evident in the case of Altona where (AATH) was greater than (ASTH) throughout the growing season, whereas the reverse situation held true for most of the growing season at the other sites. The magnitude of this effect can be observed in the yield data presented in Table 5.

At this time no concise explanation can be offered by which this heat relationship affects fababean growth. However a comparison between Equations 9 and 11 indicates that a large proportion of the heat influence is derived from the interaction between evapotranspiration and soil moisture. These equations were generated in an identical fashion with the same data set, except that in Equation 11 the accummulated heat unit variables (ASTH) and (AATH) were not included in the analysis.

Equation 9. (Data set weeks 5-11)

$$STHT = -85.34 + 0.3102(ASTH) - 0.000167(AATH)(AATH)$$

$$R^2 = 0.91 \quad S.E. = 6.2$$

Equation 11. (Data set weeks 5-11)

$$STHT = 53.61 + 26.74(AVFF) + 2.295(EVAP)(EVAP) - 0.07968(AVHF)(AVHF) - 0.001039(EVAP)(AVFF)$$

$$R^2 = 0.92 \quad S.E. = 6.1$$

Where: STHT = Stem height cm.

ASTH = Accumulated soil temperature metric heat units at 20 cm depth.

AATH = Accumulated air temperature metric heat units.

AVFF = Available soil moisture (cm) to 45 cm depth

AVHF = Available soil moisture (cm) to 105 cm depth

EVAP = Potential evapotranspiration cm.

The considerable similarity between the two equations would appear to indicate that the two sets of independent variables used are in fact highly interdependent. This would suggest that soil moisture and evapotranspiration conditions experienced in the field are quite adequately described by the interaction between accumulated levels of soil and atmospheric heat. An important observation to be made from this conclusion, in consideration of field work efficiency, is that heat data can be gathered with significantly less investment in equipment and labour time than is necessary in the collection of soil moisture data.

It would also seem likely that a further stress component described by the (ASTH) - (AATH) relationship will be that imposed in which air temperatures stimulate rapid vegetative growth that is not matched by a corresponding increase in the rate of symbiotic nitrogen fixation. This latter process is influenced by the lower soil temperature and could result in nitrogen deficiency in the plant relative to its current growth potential.

Environmental heat accumulation appears to have a further profound influence on plant development. It would appear from Tables 16 and 18 that once the soil has accumulated between 1000 and 1150 heat units, growth on the main stem will cease. Fababeans are a crop that is considered to possess an indeterminate growth habit that is rendered determinate by Manitoba's climate and it would seem that it is this soil heat accumulation factor that is responsible for initiating the physiological changes within the plant which results in a total emphasis on reproduction. This observation is given general support by Evans (1957) who reports that there is an inverse relationship between duration of high growth rates in Vicia faba and ambient temperature.

The effects of individual temperature parameters would appear to be less directly important than heat accumulation factors when equations 1-10 are considered, though a considerable degree of covariation will clearly exist between these variables and (ASTH) and (AATH). In the case of maximum temperatures (MAXC) it is possible to suggest that the observations of Evans (1957) are correct. He reported that the maximum temperature optimum for European Spring seeded varieties of Vicia faba was between 23 and 30 C. As (MAXC) rarely exceeded this optimal range during the field experimental period it is fair to suggest that fababeans are less sensitive to high ambient air temperatures than a crop such as peas (Nonnecke et al., 1971).

As far as night temperatures are concerned the failure of (MINC) to appear as a significant variable in the regression analysis can be explained by the conclusions of Listowski et al. (1966). They observed that lower night temperatures were more favourable for horsebeans but the effect of this variable was minimal in relation to the effects of variations in soil moisture. Therefore it seems reasonable to assume that though (MINC) may have had a small role in determining plant growth its effect in the regression analysis has been too small to appear as a significant variable compared to the soil moisture and heat accumulation parameters.

It is probable that a similar situation exists for the soil temperature variables examined (COIL) and (STHU) which are overshadowed in the analysis by (ASTH). Nevertheless it is interesting to observe in Equation 5 that stem growth rate is partially described by an interaction between soil and maximum air temperature rather than by air temperature alone. This illustrates the critical role of the environmental requirements of the innoculating bacteria in determining plant development.

Further evidence for the masking of individual temperature parameters in the regression analysis of the field experimental data is given by the results of growth chamber Experiment 5 (Table 14 and Figure 5). These results would appear to indicate that young fababeans are sensitive to temperature variation over a fairly narrow range and this is reflected in their growth rate. Optimum growth takes place between 15 and 23 C and fairly acute reduction occurs above and below these temperatures but growth still occurs at temperatures as low as 5 to 8 C. At very high temperatures 30 to 33 C growth takes place but at levels considerably below the optimum.

It can be concluded from the results of this experiment that the importance of (ΔST_H) and (ΔAT_H) in the field data analysis is not entirely restricted to a mere description of the effects of high potential evapotranspiration as was previously suggested in comparison of Equations 9 and 11.

The relevance of the conclusions of this section is evident in that if the level of atmospheric heat is too great, then fababean productivity will be reduced, largely as a response to soil moisture stress. Initial Manitoban yield trials by Evans et al (1972) and Seitzer (1973) suggest that reasonable yields may be obtained in certain areas. However quite considerable fluctuation in productivity occurred between 1970 and 1971. For example seed yield at Winnipeg was almost twice as large in 1971 than it was in 1970. At Morris and Glenlea very low yields were recorded in 1972 and this was ascribed to inadequate rainfall and poor root development.

On the basis of the experimental results generated in this 1974 project it would appear that a heat unit accumulation of between 1550 and 1575 units probably represents a realistic boundary beyond which fababean seed yields will be reduced unless moisture reserves are exceptional or supplemented. For silage production a long period of stem growth is desireable. Therefore an accumulation of less than 1500 heat units would appear to be a more satisfactory upper limit. The distribution of seasonal heat accumulation for Manitoba is displayed in Figure 7 and has been derived from data presented by Shaykewich (1974).

VI SUMMARY

1). Soil moisture supply, particularly that of the upper portion of the soil profile, was found to be a dominant influence in fababean productivity. It was responsible for determining the length of the growing season on the main stem after the accumulation of 1000 soil temperature heat units. Soil moisture supply was capable of reducing growth rates in the vegetative stage and the imposition of stress during the flowering or early pod set stages was found to reduce final yields. It was also suspected that low soil moisture supply in the pod filling stages could result in lower seed protein contents.

2). The interelationship between levels of accumulated heat in the atmosphere and that of the soil was found to be a critical variable in determining fababean growth performance. This was found to largely characterize the stress imposed by high potential evapotranspiration rates resulting from high air temperatures. According to the relationships developed from experimental data if unstressed growth was to take place the soil temperature heat unit accumulation had to exceed the atmospheric heat accumulation by approximately 100 units. The level of soil heat accumulation was found to be an extremely important factor in determining the length of time in which growth took place on the main stem and ultimately therefore defined the seeding to maturity growth season.

VII CONCLUSIONS

It can be concluded from this study that the physical environment has profound implications on the likelihood of successful large scale production of fababeans in Manitoba.

It is clear that excess heat, high rates of evapotranspiration and insufficient reserves of soil moisture will individually limit yields and in combination will prevent satisfactory seed or silage production. The effect of these environmental variables may be observed in Figure 8 which delimits a large area of the Province in which the full production potential of fababeans would not be realised in most years. This is based upon a seasonal atmospheric heat limit of 1550 units and a soil moisture deficit on September 30th of 20 cm. Two smaller areas, the Morden, Morris, Altona triangle and the Waskada region are also delimited by either a heat accumulation of greater than 1650 heat units or a soil water deficit on September 30th of greater than 25 cm. These two areas are considered to be of only limited potential for production of this crop.

This map indicates that the area of the Province regarded as suitable for successful annual production of fababeans is considerably reduced. Therefore in future general crop recommendations for fababeans it would be advisable for a considerable degree of caution to be excercised.

This conclusion is particularly applicable for the previously recommended practice of very early seeding. This would appear to be undesireable due to the existence of a large temperature differential between soil and atmosphere in early Spring. Further support for later seeding is given by Simons (1974) whose research into the germination of fababeans indicated that minimum soil temperature requirements were between 10 and 12 C. These soil temperatures are not normally experienced under very early seeding conditions at 5 cm depth in Manitoba.

In order to assess the true impact of the physical environment on fababean production, it is important to appreciate that the findings of this study are based on data from only one growing season. This clearly limits the initial confidence with which prediction of fababean growth performance can be made from the relationships generated in this study. It is therefore important that at least two further years of research is performed to investigate the studies' validity and to refine its conclusions. This data would also enable determination of crop productivity under varying environmental conditions on a basis of seed yield rather than dry matter production. It would also be possible to develop a fababean growth unit based upon the particular temperature requirements of the crop which would result in the development of a more reliable productivity potential map. Further research would also seem to be necessary in evaluating the influence of soil moisture availability and environmental temperature on the protein content of grain and silage. This would aid prediction of the quality of fababean crops and consequently allow assessment of potential vegetable protein production from fababeans per unit area of Manitoba.

TABLE 1.

SITE DESCRIPTION

Location	Legal Description	Soil Association	MHU	SWD	Seeding Date
Altona	SE-24-02-02W	Altona	1650	20	27/5/74
Pilot Mound	SE-16-03-11W	Snowflake	1485	5	1/6/74
Seven Sisters	SW-28-13-11E	Framnes	1500	12	10/6/74

where:

MHU = Mean atmospheric heat accumulation above 5 C May 1st to September 30th.
SWD = Mean soil water deficit (cm) on September 30th.

TABLE 2.

DESCRIPTION OF FIELD EXPERIMENT SOILS

Site	Texture	Nitrate* (kg/ha)	Available* P. (ppm)	Available* K. (ppm)
Altona	Very fine sandy loam	51	3.7	265
Pilot Mound	Clay loam	54	2.8	356
Seven Sisters	Clay loam	65	1.9	154

* = Sampled to 120 cm depth.

TABLE 3.

GROWTH CHAMBER EXPERIMENTS 1 AND 2, SOIL DESCRIPTION

Soil	Texture	pH	Nitrate N. (ppm)	Available P. (ppm)	Available K. (ppm)
Almasippi	Loamy fine sand	7.2	14.8	35.8	343
Red River	Clay	7.6	15.6	11.0	550

TABLE 4.

DRY MATTER PRODUCTION

Weeks After Seeding	Accumulated Total Dry Matter (q/ha)			Accumulated per Plant Dry Matter (gm/pl.)			Relative Growth Rate (RGR) (q/ha.wk)		
	A	PM	7S	A	PM	7S	A	PM	7S
3			2.4			0.5			1.4
4	1.9	7.5	6.7	0.3	1.4	1.5	1.5	4.0	4.3
5	6.0		13.2	1.1		3.0	4.1		6.5
6	12.8	20.2	19.4	2.3	3.2	4.4	6.9	12.2	6.2
7	28.5	36.9	30.8	5.1	5.8	7.0	15.6	16.7	11.5
8	31.1	62.6	44.0	5.5	9.8	10.0	2.7	25.7	13.2
9	28.6	79.5	49.4	5.1	12.4	11.2	0.0	16.9	5.4
10	33.4	84.3	64.8	5.9	13.2	14.7	4.7	4.9	15.4
11	35.5	70.6	80.6	6.3	11.0	15.3	4.1	0.0	15.8
12	37.5	69.3	90.1	6.7	10.8	20.5	4.1	0.0	9.5
13	40.7	69.5	101.5	7.3	10.9	23.1	3.2	0.0	10.4
14	46.0	69.7	101.0	8.2	10.9	22.8	5.1	0.0	0.0
15			92.6			21.1			0.0

Where: A = Altona, PM = Pilot Mound and 7S = Seven Sisters.

TABLE 5.

FINAL YIELD DATA

Site	Variety	Final Seed wt. (q/ha)	Final Seed wt/pl (gm)	Protein Content %	Protein Yield (q/ha)
PM.	Diana	26.2	4.1	25.0	6.55
7S.	Diana	23.0	5.2	34.1	7.84
Al.	Ackerperle	13.1	2.3	30.5	3.99

TABLE 6.

FINAL YIELD CHARACTERISTICS

Site	Mean Number of Plants per Sq.m	Mean Number of Pods per plant	Mean Number of Seeds per pod	1000 Seed Weight (gm)
Pilot Mound	64	7.3	3.3	158.6
Seven Sisters	44	10.9	3.0	280.8
Altona	56	4.8	3.0	280.5

TABLE 7.

STEM AND NODE DEVELOPMENT

Weeks After Seeding	Stem Height (cm)			Stem Growth Rate (cm/day)			Number of Nodes		
	A	PM	7S	A	PM	7S	A	PM	7S
3	1.7		9.2	0.25		1.05	3.0		6.0
4	9.9	10.0	16.2	1.15	0.70	1.00	5.0	7.0	9.6
5	16.8	22.0	28.8	0.98	1.70	1.81	10.0	10.0	14.7
6	26.3	40.3	45.0	1.35	2.07	1.77	10.4	13.0	18.2
7	35.5	55.0	52.6	1.35	2.14	1.77	16.6	17.0	21.1
8	45.8	71.9	69.4	1.01	2.20	2.04	20.5	21.0	23.7
9	47.4	75.8	78.5	0.40	0.70	1.19	20.1	22.0	25.0
10	50.6	72.2	82.5	0.30	0.20	0.52	20.0	24.0	26.0
11	46.2	72.2	84.4	0.00	0.00	0.25	19.5	24.0	27.0
12	49.4	72.2	86.3	0.45	0.00	0.31	21.2	24.0	28.0
13	49.7	72.2	87.0	0.00	0.00	0.00	21.0	24.0	28.5
14	50.0	72.2	92.0	0.00	0.00	0.57	21.1	24.0	31.8
15			89.4			0.00			30.9

TABLE 8.

CLIMATIC DATA

Weeks After Seeding	Rain (cm)			Mean Weekly Max.Temp C.			Mean Weekly Min.Temp C.			Potential Evapotranspiration (cm)			Accumulated Heat units (AATH)		
	A	PM	7S	A	PM	7S	A	PM	7S	A	PM	7S	A	PM	7S
2	0.1	0.1	0.0	20.3	19.6	26.7	9.2	7.0	9.5	2.74	2.85	3.76	141	115	136
3	0.1	0.9	0.0	23.0	23.4	28.5	7.5	9.1	11.5	3.35	3.36	4.01	209	192	239
4	0.8	0.0	1.5	27.8	27.3	30.5	12.0	12.8	15.2	3.91	3.68	4.19	313	290	356
5	1.2	0.1	1.0	30.5	26.2	29.0	15.0	12.5	13.6	4.22	3.68	3.91	433	398	467
6	0.6	0.5	2.9	30.6	28.5	29.7	17.0	17.5	14.6	3.99	3.59	4.09	559	509	586
7	1.2	0.0	0.7	30.1	28.9	22.4	17.0	14.4	11.3	3.57	3.73	2.57	682	626	672
8	0.1	0.0	0.2	31.2	29.0	26.8	17.3	15.5	9.0	4.04	3.60	3.66	813	733	751
9	0.5	0.0	2.8	26.7	24.1	23.6	12.8	16.5	12.5	3.38	3.37	2.82	914	825	828
10	1.2	0.5	3.2	26.6	25.3	19.9	15.6	13.0	9.8	3.10	3.33	1.96	1020	911	892
11	3.2	1.3	1.9	25.6	24.1	18.1	14.5	10.7	8.9	2.59	2.81	1.52	1131	978	952
12	5.1	5.2	2.0	23.2	20.0	15.8	12.0	8.1	4.8	2.29	2.31	1.19	1226	1022	981
13	0.5	1.0	1.8	21.7	21.1	15.0	9.3	7.2	7.5	1.98	1.90	1.27	1308	1061	1030
14	1.1	0.5	1.7	17.0	17.0	15.5	8.2	4.3	4.5	1.50	1.65	0.94	1354	1096	1061
15			0.4			12.8			0.5			0.61			1085

TABLE 9.

SOIL WATER AVAILABILITY

Weeks After Seeding	Available Water to 30 cm (cm)			Available Water to 45 cm (cm)			Available Water to 105 cm (cm)		
	A	PM	7S	A	PM	7S	A	PM	7S
0	4.30	5.54	3.04	6.81	8.50	4.78	23.93	18.72	12.55
1	3.78		2.34	6.08		4.66	22.24		13.99
2	1.80	4.31	2.23	4.05	7.21	4.52	19.66	16.42	13.51
3	1.55	3.75	1.55	3.78	6.52	3.80	19.64	14.93	12.78
4	1.43		1.34	3.64		3.29	19.33		12.10
5	1.09	2.00	1.33	3.16	4.50	2.95	18.58	11.00	11.61
6	0.98	1.36	1.27	2.88	3.52	2.39	17.91	8.95	10.19
7	0.57	0.72	1.10	2.29	2.29	2.03	16.55	6.47	8.87
8	0.28	0.28	0.70	1.84	1.27	1.24	15.72	4.49	6.63
9	0.14	0.01	1.42	1.48	0.51	2.13	14.58	2.96	7.98
10	0.35	0.00	2.10	1.68	0.16	3.06	13.69	1.71	9.56
11		0.00			0.14			1.55	
12	2.40	1.12	2.25	4.05	1.24	3.58	16.63	2.48	8.68
13	0.89			2.49			14.61		
14	0.89	0.89	2.86	2.48	1.35	4.77	14.24	3.75	10.89
15			2.55			4.17			9.16

TABLE 10.

SOIL TEMPERATURE DATA FROM 20 CM DEPTH

Weeks After Seeding	Weekly Soil Temperature C. at 20 cm (COIL)			Weekly Soil Temperature C. Heat Units (STHU)			Soil Heat Unit Accumulation (ASTH)		
	A	PM	7S	A	PM	7S	A	PM	7S
1	11.0	12.1	13.2	42	49	57	42	49	57
2	12.8	13.9	18.8	54	62	96	96	111	154
3	17.0	19.7	22.0	84	103	119	180	214	273
4	21.0	19.7	19.9	112	103	104	292	317	377
5	22.2	20.0	21.6	120	105	116	413	422	493
6	22.9	21.3	22.4	125	114	121	538	536	615
7	22.8	22.6	18.9	124	123	97	662	659	712
8	24.7	18.5	18.0	140	94	91	800	753	803
9	20.0	17.9	17.5	105	90	87	905	844	891
10	19.8	20.4	15.8	103	108	75	1009	952	966
11	17.8	16.2	14.7	89	78	68	1099	1030	1034
12	16.9	13.6	12.7	83	60	54	1182	1090	1088
13	14.5	11.5	11.1	66	45	42	1248	1136	1131
14	11.4	10.6	9.4	45	39	31	1293	1175	1167
15			7.5			18			1185

TABLE 11.

THE INFLUENCE OF SOIL MOISTURE AVAILABILITY ON YIELD GROWTH CHAMBER EXPERIMENT 1.

Soil	Treatment A.W.R.	Mean Dry Wt/pot gm	Mean Seed Wt/pot gm
Almasippi	100-25%	97.0	24.6
	100-50%	103.1	24.5
	100-75%	100.6	21.7
	100-25% & 100-75%	102.8	21.7
	100-50% & 100-75%	95.4	25.6
Red River Clay	100-25%	10.9	1.8
	100-50%	8.5	1.3
	100-75%	11.3	1.0
	100-25% & 100-75%	16.2	1.7
	100-50% & 100-75%	8.3	0.8

where A.W.R. = Available water regime.
Day/night temperature regime was 15/10 C.

TABLE 12.

THE INFLUENCE OF SOIL MOISTURE ON STEM GROWTH RATE RESULTS OF GROWTH CHAMBER EXPERIMENT 3.

Soil	Treatment AWR.	Mean Stem Growth Rate cm/wk.
Altona	100-0%	7.37
	100-66.6%	6.88
	100-33.3%	8.88
Pilot Mound	100-0%	7.38
	100-33.3%	12.87
Seven Sisters	100-0%	6.51
	100-66.6%	12.00
	100-33.3%	10.12

where: AWR = Available water regime.
Day/night temperature regime was 20/15 C.

TABLE 13.

THE INFLUENCE OF SOIL MOISTURE AVAILABILITY ON YIELD RESULTS OF GROWTH CHAMBER EXPERIMENT 4.

Soil	Treatment AWR.	Total Dry Weight/pot gm.
Altona	100-0%	7.9
	100-66.6%	15.5
	100-33.3%	29.1
Pilot Mound	100-0%	12.0
	100-33.3%	22.5
Seven Sisters	100-0%	10.2
	100-66.6%	13.9
	100-33.3%	13.8

Where: AWR = Available water regime.
Day/night temperature regime was 20/15 C.

TABLE 14

THE EFFECT OF AMBIENT TEMPERATURE ON DRY MATTER PRODUCTION

Temperature C	Weight gain per plant (gm)	Percentage weight gain %
5-8	0.037	18.8
10-13	0.050	25.9
15-18	0.134	74.0
20-23	0.162	79.4
25-28	0.070	36.3
30-33	0.066	24.5

TABLE 15.

PREDICTED PLANT DRY WEIGHT GM.

ASTH	AATH	Available water (cm) to 105 cm.			
		6 cm	10 cm	12 cm	14 cm
700	600	13.8	14.1	15.1	16.7
900	800	15.2	15.5	16.4	18.1
1100	1000	15.8	16.0	17.1	18.6
1300	1200	15.4	15.7	16.7	18.3

where: ASTH = Accumulated soil temperature heat units at 20 cm depth.
AATH = Accumulated air temperature heat units.

The Table is derived from Equation 1.

EVAP is assumed to be constant at the seasonal mean value of 3.3 cm.

TABLE 16.

PREDICTED STEM GROWTH RATE (CM/DAY)

	Available water (cm) to 30 cm.					
ASTH	2.5 cm	2 cm	1.5 cm	1 cm	0.5 cm	0.25 cm
400	1.62	1.39	1.15	0.92	0.67	0.56
500	2.15	1.92	1.68	1.44	1.20	1.09
600	2.45	2.21	1.97	1.74	1.50	1.39
700	2.50	2.27	2.03	1.80	1.56	1.45
800	2.33	2.01	1.86	1.61	1.37	1.34
900	1.91	1.68	1.44	1.20	0.96	0.85
1000	1.26	1.03	0.79	0.55	0.31	0.20
1050	0.84	0.62	0.38	0.14	0.00	0.00
1100	0.37	0.14	0.00	0.00	0.00	0.00
1150	0.00	0.00	0.00	0.00	0.00	0.00

where: ASTH = Accumulated soil temperature heat units at 20 cm depth.

The Table is derived from Equation 10.

EVAP is assumed to be constant at the seasonal mean value 3.3 cm.

TABLE 17.

PREDICTED NUMBER OF DIFFERENTIATED NODES

AVFF (cm)	Accumulated Soil Temperature Heat Units. 700	800	900	1000	1100	1200	1300	1400
0.25	20.9	22.0	22.8	23.6	23.5	23.2	22.5	21.6
0.50	21.8	22.9	23.8	24.3	24.5	24.5	24.1	23.5
0.75	22.8	23.9	24.7	25.3	25.5	25.4	25.1	24.5
1.00	23.8	24.9	25.7	26.2	26.5	26.4	26.1	25.4
1.50	25.7	26.8	27.6	28.2	28.3	28.3	28.0	27.4
2.00	27.6	28.8	29.6	30.1	30.3	30.3	29.9	29.3
2.50	29.6	30.7	31.5	32.0	32.2	32.2	31.9	31.2
3.00	31.5	32.6	33.4	34.0	34.1	34.1	33.8	33.2
3.50	33.4	34.6	35.4	35.9	36.1	35.7	35.1	34.6
4.00	35.3	36.4	37.2	37.7	38.0	37.9	37.6	37.0

Where: AVFF = Available soil moisture (cm) to 45 cm depth.

The Table is derived from Equation 3.

EVAP is assumed to be constant at the seasonal mean value 3.3 cm.

AVHF is assumed to be constant at the seasonal mean value of 11.2 cm.

TABLE 18.

PREDICTED STEM HEIGHTS (CM)

	Accumulated soil temperature heat units.								
AATH	600	700	800	900	1000	1100	1200	1300	1400
400	74.1								
500	59.0	90.1							
600	40.7	72.9	102.7						
700	19.0	50.0	81.0	112.0					
800		24.8	55.9	86.9	117.8				
900			27.6	58.6	89.6	120.6			
1000				26.8	57.9	88.9	119.9		
1100						53.8	84.8	115.9	
1200							48.5	77.4	108.5
1300								35.6	66.7

where AATH= Accumulated air temperature heat units.

The Table is derived from Equation 9.

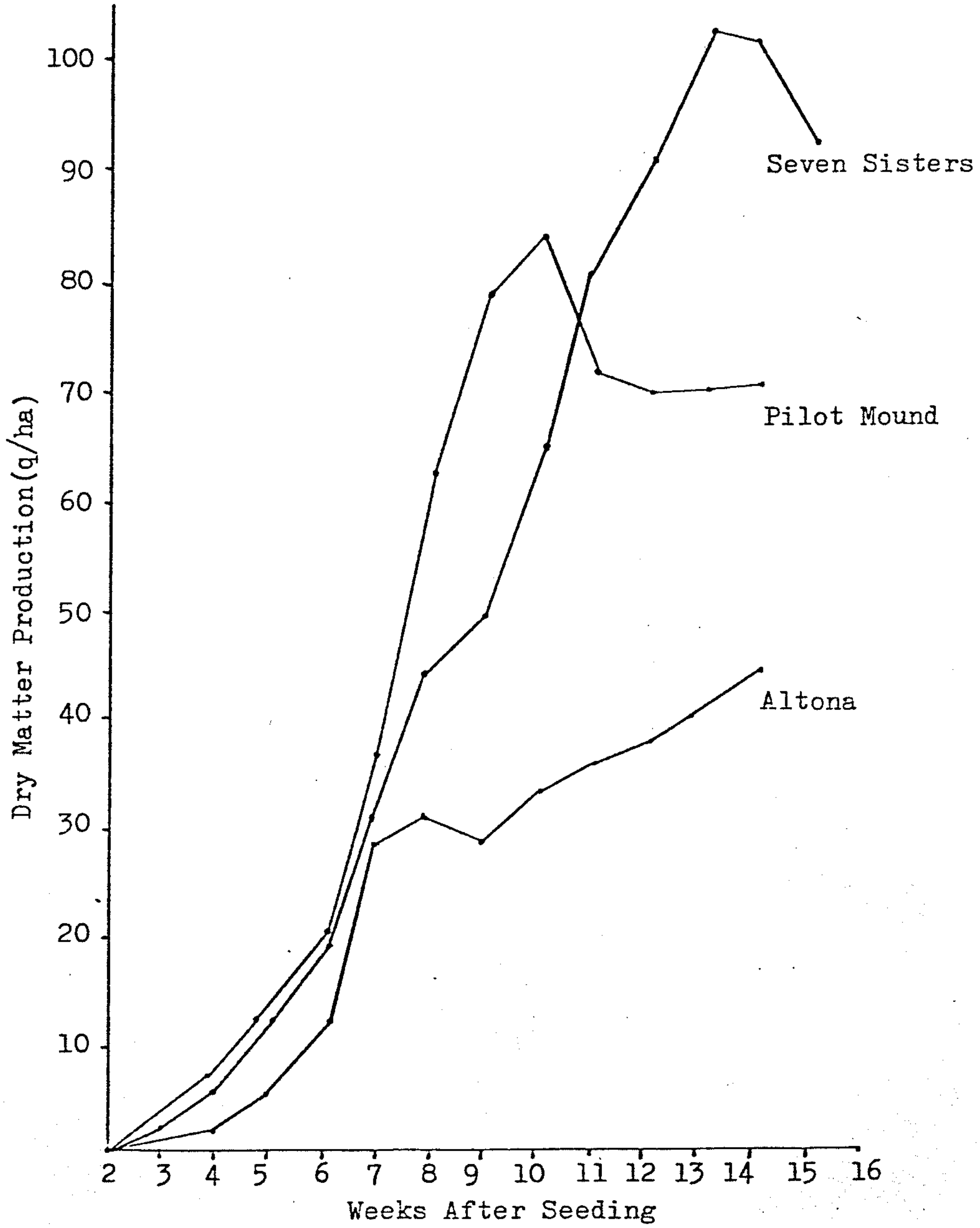

FIGURE 1. DRY MATTER PRODUCTION

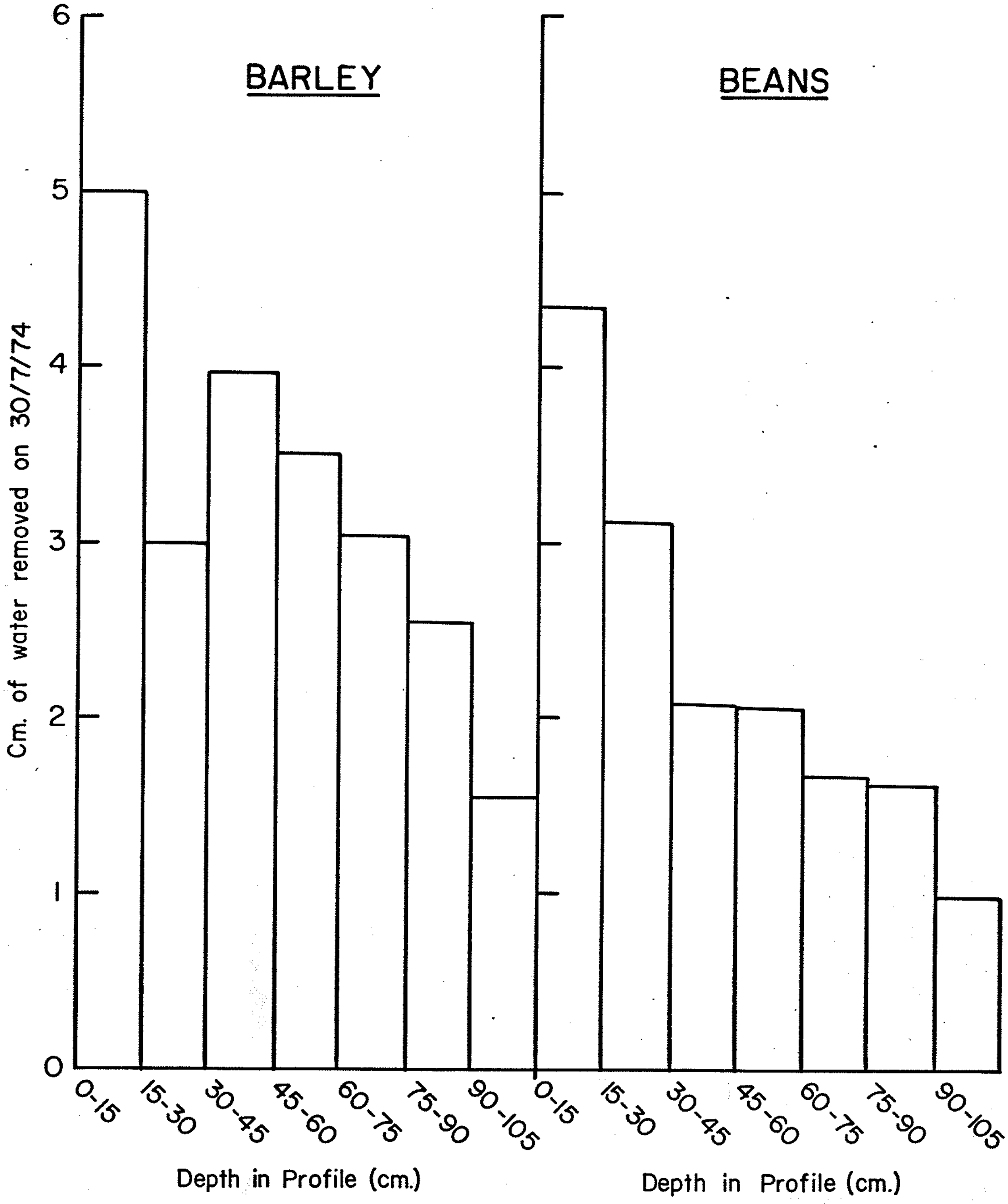

FIGURE 2. WATER WITHDRAWAL PATTERN AT ALTONA ON 30/7/74

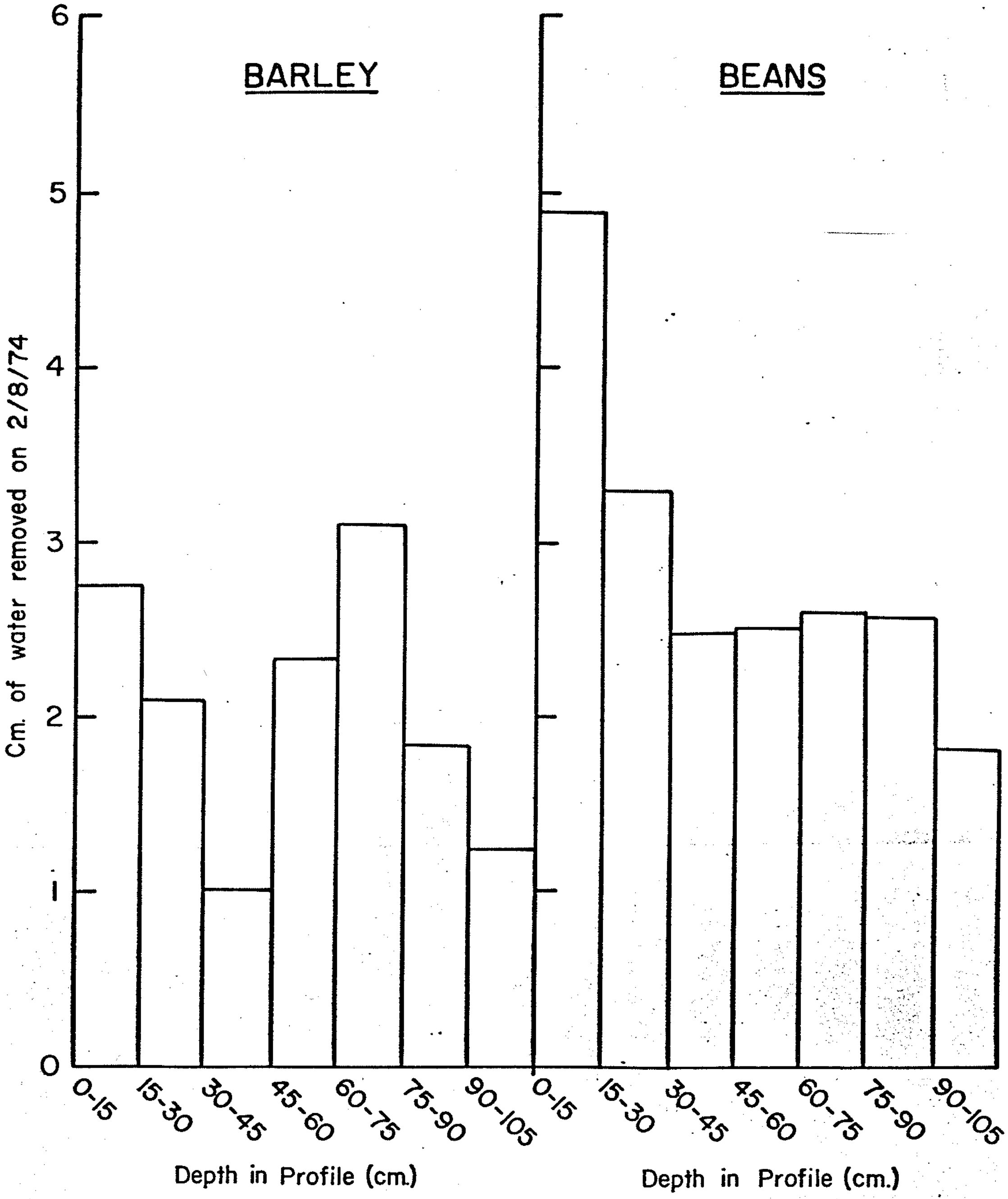

FIGURE 3. WATER WITHDRAWAL PATTERN AT PILOT MOUND ON 2/8/74

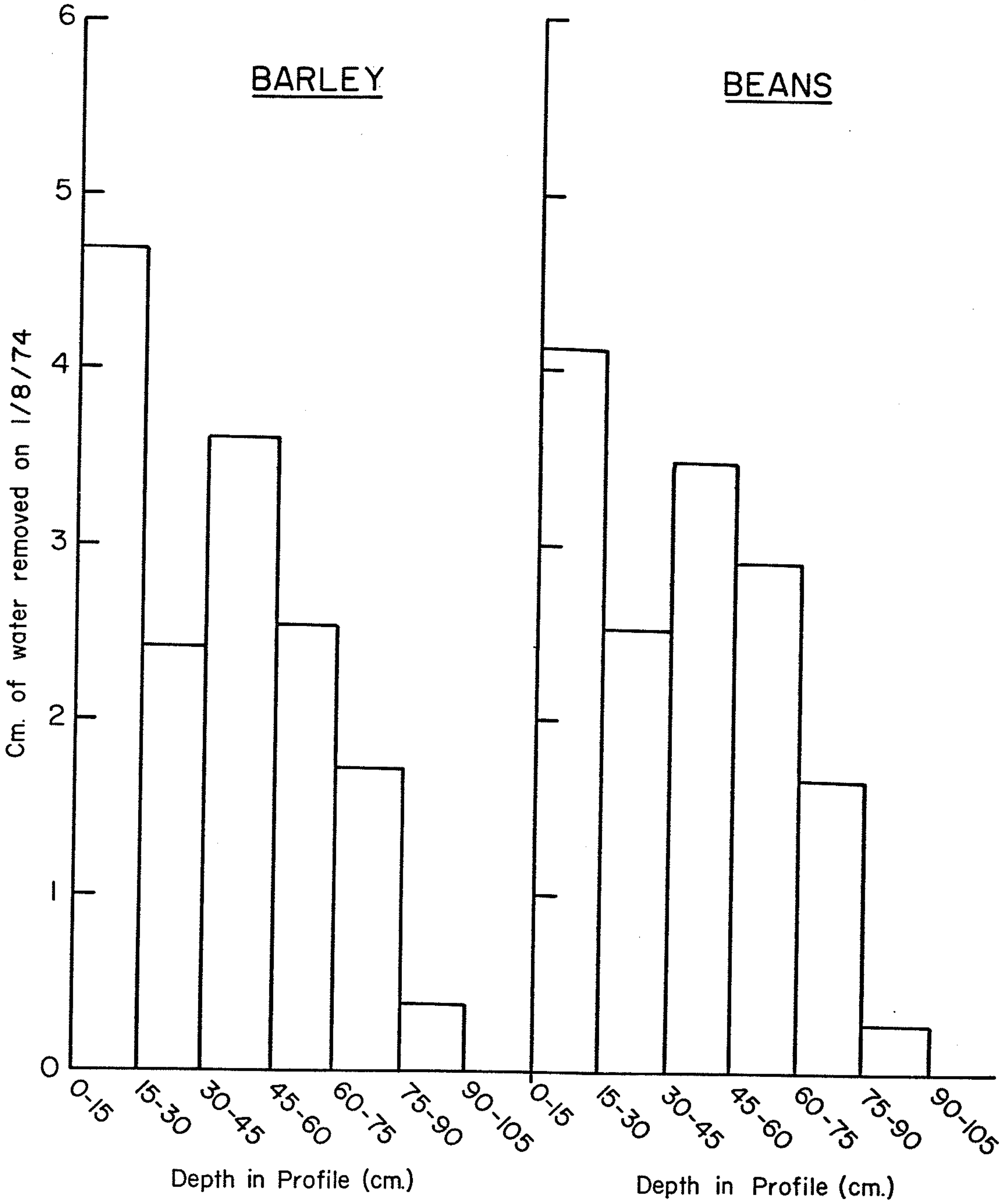

FIGURE 4. WATER WITHDRAWAL PATTERN AT SEVEN SISTERS ON 1/8/74

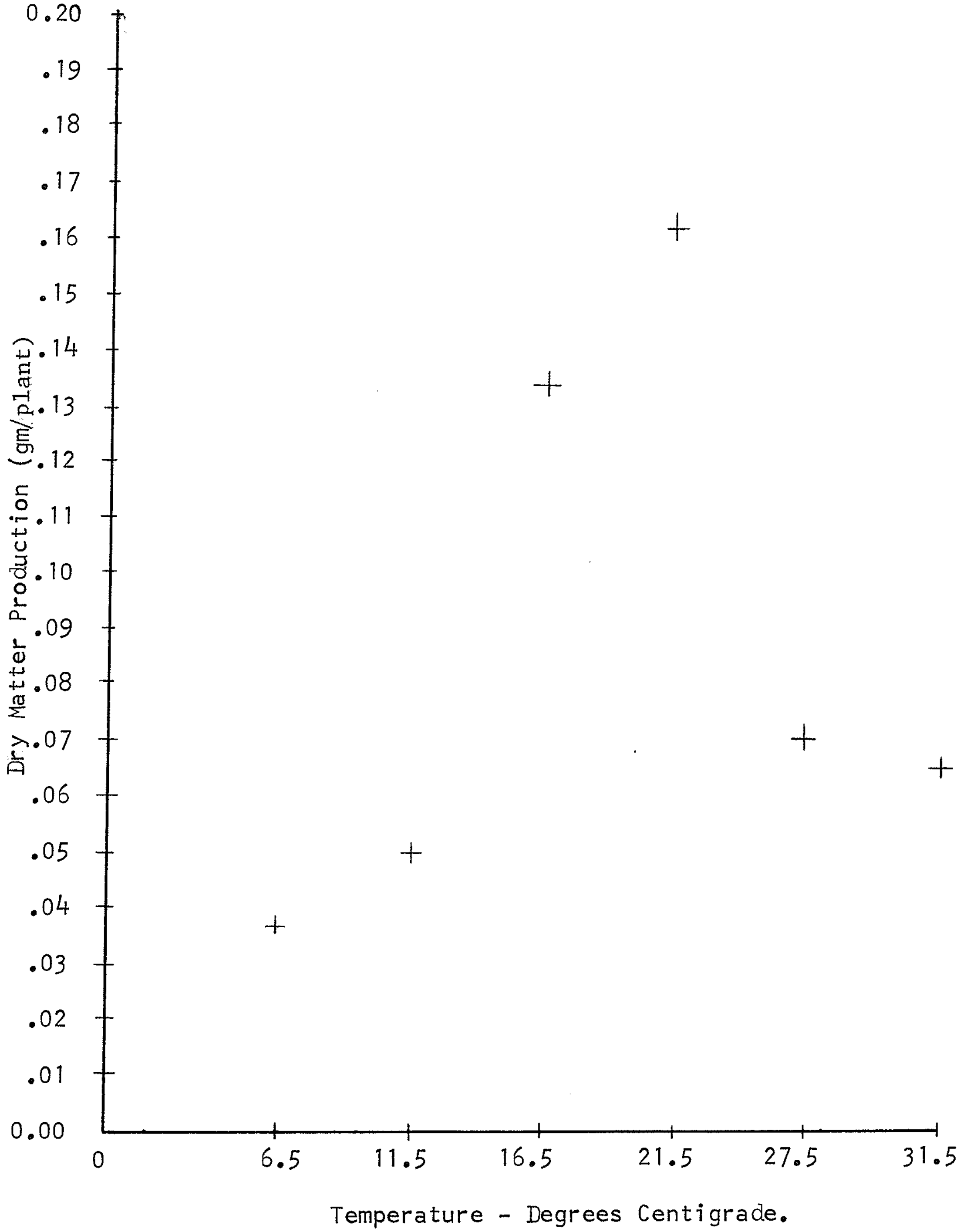

FIGURE 5. THE INFLUENCE OF AMBIENT TEMPERATURE ON GROWTH

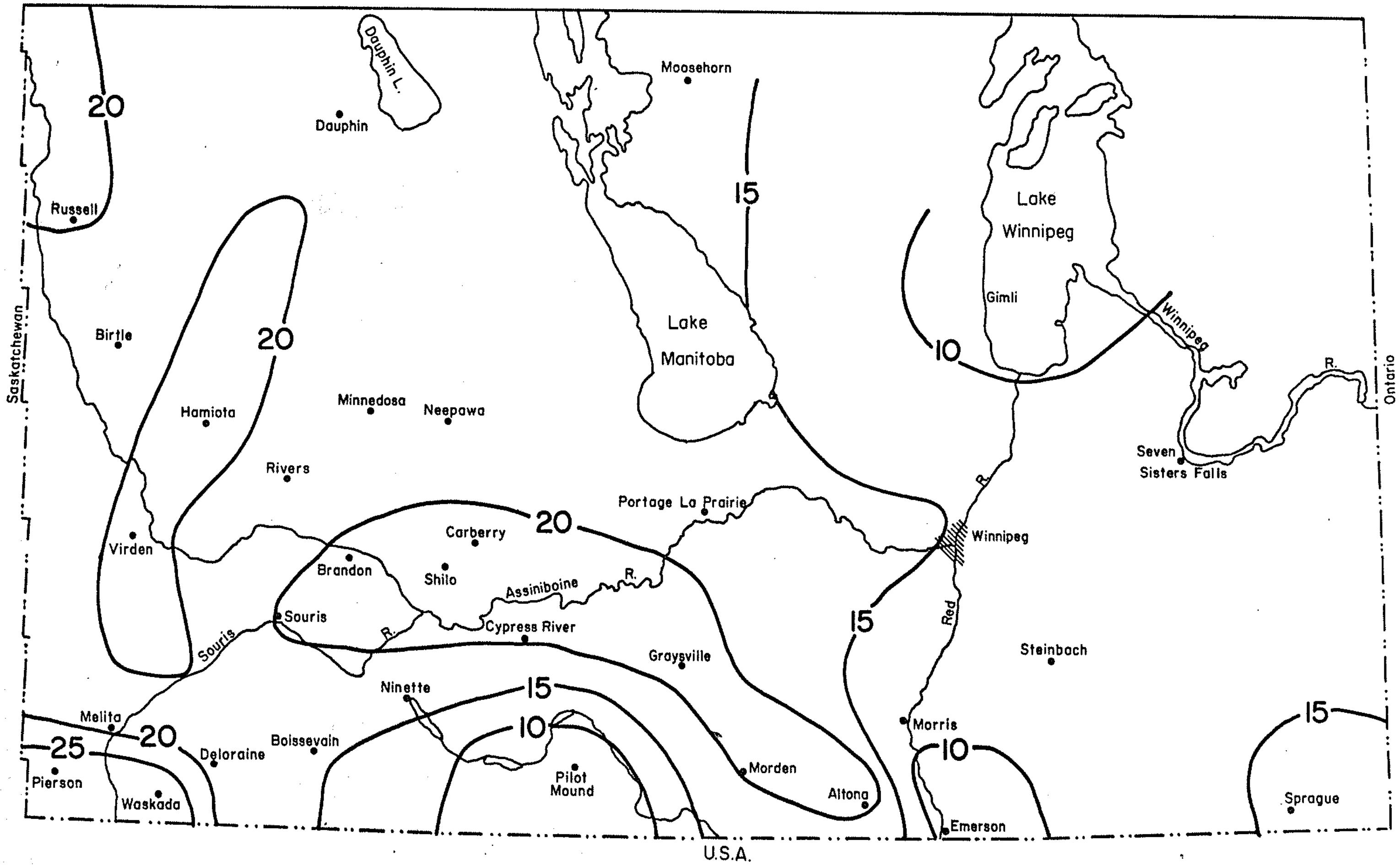

FIGURE 6. SOIL WATER DEFICIT (CM) ON SEPTEMBER 30TH

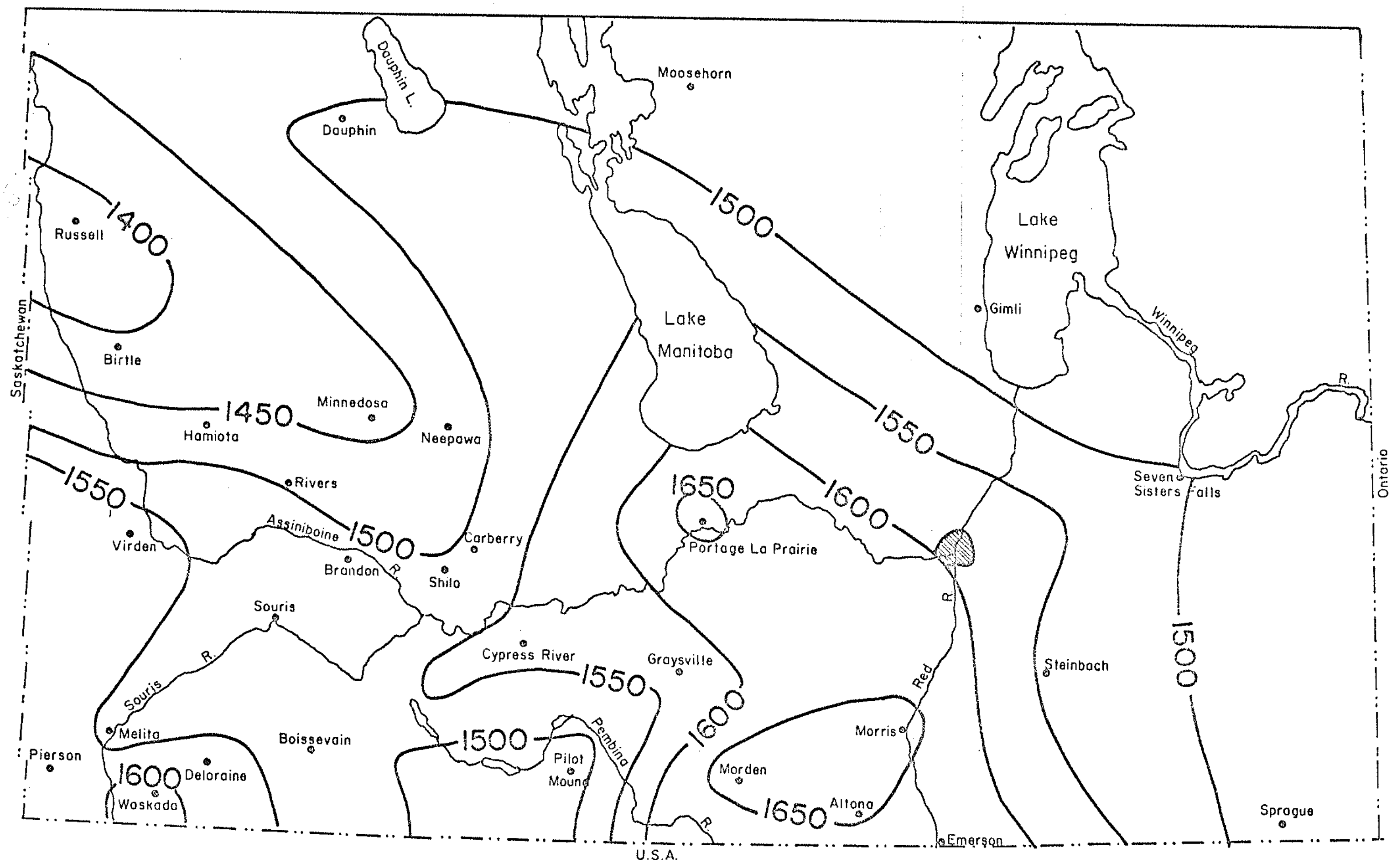

FIGURE 7. ATMOSPHERIC HEAT UNITS ABOVE 5.5 C MAY 1st to SEPTEMBER 30th

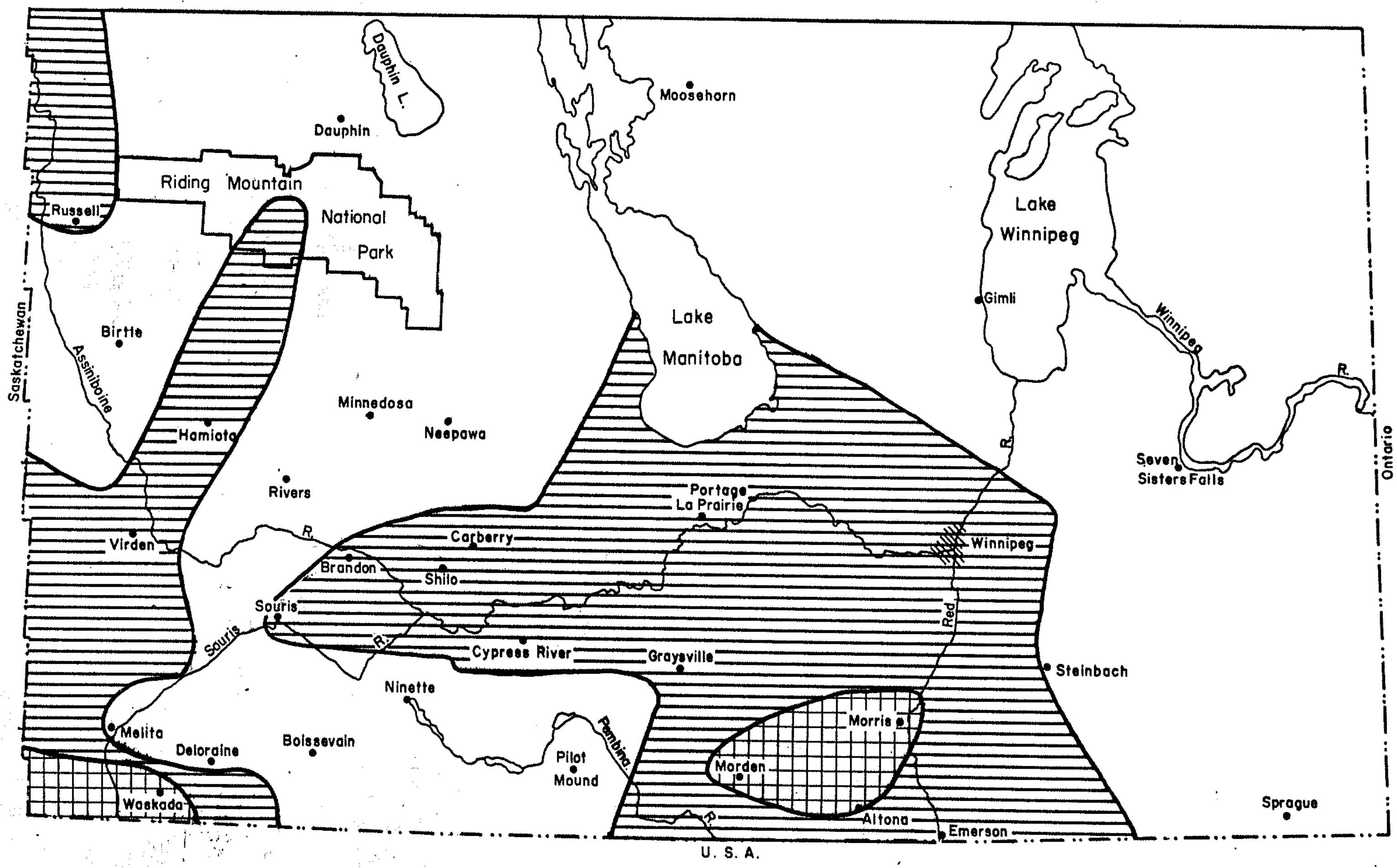

FIGURE 8. FABABEAN PRODUCTION POTENTIAL IN MANITOBA

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