Water Table Management Strategies For Soybean Production

by

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Abstract

MSc. **Agricultural Engineering**

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Water Table Management Strategies For Soybean Production

A field lysimeter experiment was conduc~ed on a sandy loam soil during the growing seasons of 1989 and 1990. The experiment tested the effects of fou water table treatments on soybean (Glycine max) yields. The water table depths were 40, 60, 80, and 100 cm in depth.

Yields were measured in terms of: total seed mass per plant, number of seeds per plant, number of pods per plant, number of seeds per pod, and seed protein content at harvest.

The water management simulation model DRAINMOD, was used to develop irrigation and drainage strategies for soybean production. Twenty four years of rainfall data was used for the simulations. The once in 24 wet and dry years, and the average of the 24 years was considered in depth. Three water table management methods were tested with each of three water table depths. The methods were conventional drainage, controlled drainage, and subirrigation, and the water table depths were 40, 60, 80, and 100 cm.

Experimental results found in the 1990 growing season were somewhat scattered, but their trends compared favourably with those found in simulations. It was shown that for the driest year highest yields are obtained with subsurface irrigation and a weir setting of 40 cm. For the average year, highest yields are obtained with subirrigation and a 60 cm weir setting. For the wet years, best results are found when controlled drainage is used with 80 cm weir setting. It was found that in all but the driest and wettest years controlled drainage improved yields by 10 % or more. This a significant increase considering the low inputs required.

Sommaire

Msc.

Agricultural Engineering

Stephen Broughton

Strategies de Gestion de la Nappe d'eau pour la production du Soja

On a effectué une experience utilisant des lysimetres et un sol limono-sableux, pendant les saisons de croissance 1989 et 1990. On a étudié les effets de quatre nappes d'eau, 40, 60, 80, et 100 cm.

Les paramètre qui furent mesurés sont: masse totale des graines par plant, nombre de graines par plant, nombre de cosses par plant, nombre de graines par cosse, et le taux de protéine des graines à la récolte.

Utilisant 24 années de données climatiques, le modèle DRAINMOD a été employé pour déterminer les effets des différentes méthodes de gestion de la nappe d'eau, sur le rendement relatif du soja.

On a étudié plus en détail trois années parmi les vingt-quatres années, soit l'année la plus sêche, l'année la plus humide, et l'année moyenne. On a considéré trois méthodes de gestion de l'eau, chacune avec trois profondeurs de nappe d'eau différentes. Les méthodes de gestion de l'eau furent: le drainage normal, le drainage contrôlé, et l'irrigation sousterraine. Les nappes d'eau ont été contrôlées par des déversoirs ayant 3 niveaux d'ecoulement différents: 40, 60, et 80 cm.

Les résultats experimentaux de 1990, ressemblaient beaucoup aux simulations de l'année la plus humide. Les simulations ont données les resultats suivants: 1) pour l'année moyenne l'irrigation et le déversoir a 60 cm de la surface a donné les plus hauts rendements. 2) pour les années humides le drainage controlé et le déversoir à 80 cm a donné les meilleures resultultats. 3) à long terme, l'irrigation souterraine avec le déversoir à 60 cm donne les meilleurs rendements. Pour les années sèches, la meilleure combinaison est l'irrigation souterraine avec le déversoir à 40 cm de la surface. On a trouvé que, pour une année moyenne les rendements peuvent être ameliorés de 10 % avec le drainage controlé; ce qui est significatif si on considére l'effort requis pour l'obtenir.

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Nomenclature

A, B	:	Green - Ampt parameters
C	:	degrees Celsius
cc	:	water level control chamber
cm	:	centimetre
CV	:	coefficient of variability
d	:	day
DC	:	drainage coefficient (cm/d)
ET	:	actual evapotranspiration
ha	:	hectare
hr	:	hour
ID	:	inside diameter
k	:	saturated hydraulic conductivity
k_p	:	evaporation pan coefficient
k_c	:	crop consumptive use coefficient
kg	:	kilogram
m	:	metre
m^2	:	square metre
m^3	:	cubic metre
mm	:	millimetre
N_2	:	Nitrogen gas
PET	:	potential evapotranspiration
PE	:	polyethylene
PVC	:	polyvinyl chloride
%	:	percent
R1 to R7	:	soybean reproductive growth stages
SAS	:	Statistical Analysis System
STD	:	standard deviation
V	:	soybean vegetative growth stage

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1.0 INTRODUCTION

Soybeans are often grown in regions of North America where there is an average annual moisture surplus. However, the middle of the growing season could be very dry. Therefore, supplemental irrigation could be beneficial. Interest in soybean as an irrigated crop is increasing. Irrigation of soybean has increased seed yield and can increase profits where moisture deficits occur (Heatherly, 1988) More research is required concerning production potentials associated with irrigation management requirements for specific regions.

In Quebec, the climate is such that there is often an excess of soil water in the spring due to snowmelt, and also in autumn when rainfall is in excess of evapotranspiration. During these times removal of excess soil water is critical for the planting and harvesting of crops. For these reasons farmland is made more productive through the installation of subsurface drainage systems. By modifying the existing subsurface drainage systems as well as installing new water management systems better yields can be achieved.

In 1990, there were 18,200 ha in soybean production in Québec, compared to 1,439 in 1981 and 4,395 ha in 1986 (Gouvernment du Québec, 1981-1986, 1990). As the area under soybean increases, so does the interest in improving yields, and management practices. Irrigation has a generally positive effect on increasing soybean yields according to Doss and Thurlow (1974). However Matson (1964) found that soybean response to irrigation was often highly variable and only really useful if other management practices were also improved. Much of the increased acreage of soybean is grown on land that was previously under corn or rotational crops. Adequate drainage is essential for the production of soybean, because small plants can easily be killed if there is a lack of oxygen in the root zone due to excess soil water. Well drained soils also allow more trafficable days per year. Therefore crops can be planted earlier, and harvested on time. It may also be feasible to use existing drainage systems for providing supplemental irrigation water.

Controlled drainage and subsurface irrigation are two methods of artificially maintaining a water table in the soil. Controlled drainage is a method of limiting the amount of water leaving the soil through a conventional drainage system, during periods of excess soil water. This technique is described by Doty *et al.* (1975).

Subsurface irrigation is the addition of irrigation water to the drainage system via water control chambers, on collector or lateral lines. Water moves upward by capillary rise from the water table to the root zone. Figure 1.1 shows the water table shapes that could be expected under subsurface drainage, while Figure 1.2 shows the water table shape for the subirrigated case. Water table shapes are exaggerated, as a result of the very small drain spacing the difference of water table elevation

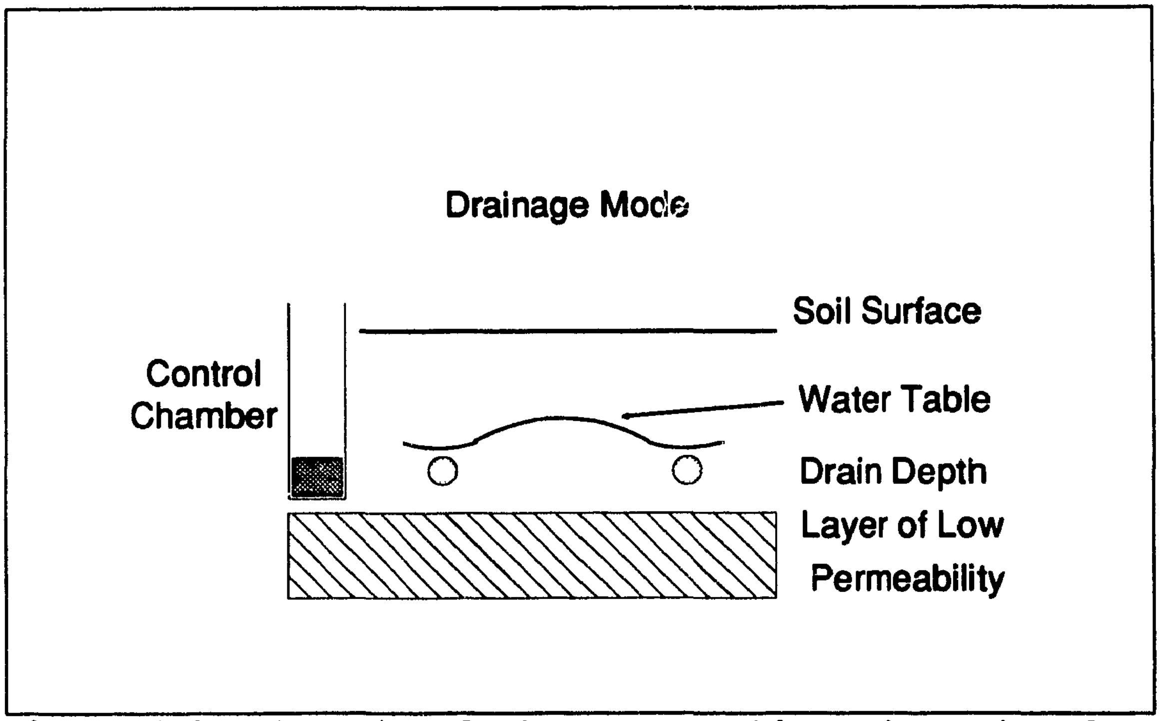

Figure 1.1 Schematic of the water table under subsurface drainage.

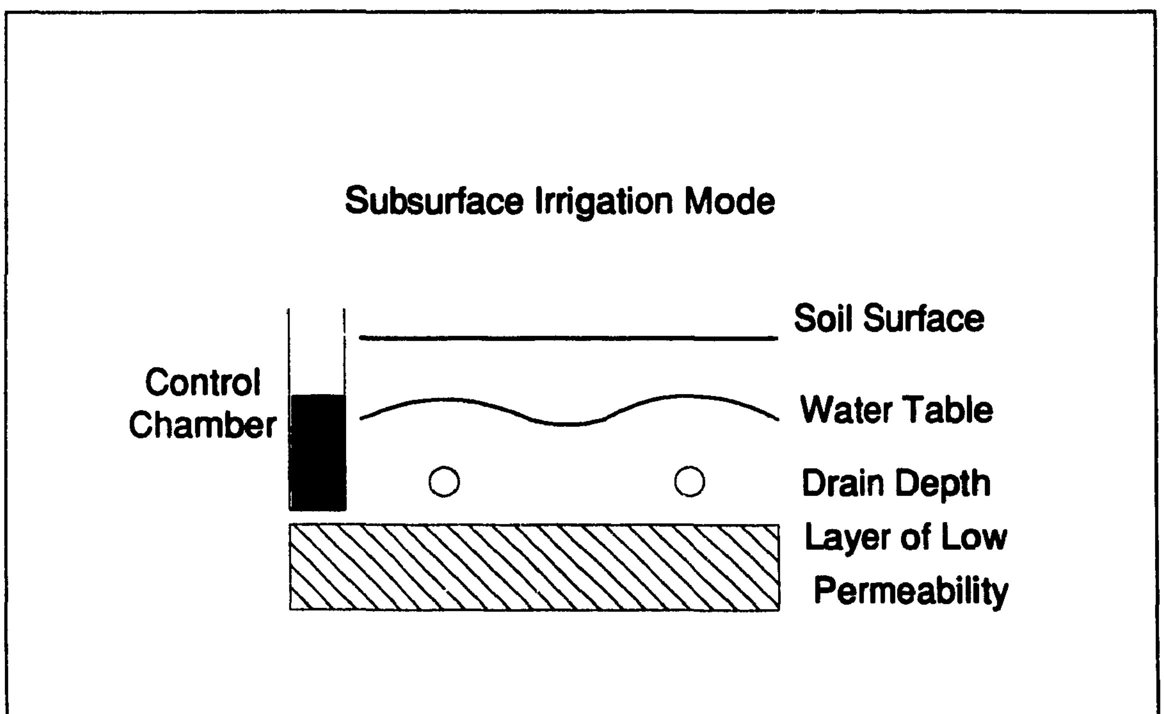

Figure 1.2 Schematic of the water table under subsurface irrigation.

at midspacing and above the drains. The actual deflections are usually less than 30 cm depending on the soil type and drain spacings.

Subirrigation has low energy requirements because of the low pressures involved. To irrigate field crops using overhead sprinklers is much more costly, due to the equipment required to bring water at high pressure to run the sprinklers and water guns. Subirrigation requires low flows for long periods, or even for 24 hours a day. The pressure need only be sufficient to overcome the lift from the source to the water level control chamber.

Subirrigation also offers a method of regulating runoff and dissolved chemicals that could enter into watercourses. Maintaining a high water table has been shown to reduce the loss of nitrates and other minerals. (Skaggs *et al.,* 1972). Subsurface irrigation has lower energy costs, as well as the potential to reduce water pollution.

Until recently, there has been a lack of reliable design criteria for subirrigation systems. Fox *et al.* (1956) were amongst the first to establish design standards. When calculating the drain lateral spacing of a combined subsurface drainage/subirrigation system , Skaggs (1979) stated that three cases must be considered:

1) Steady state: The system must be able to keep the water table at a constant position under high evapotranspiration.

2) Transient state: The water table should be raised from a low position to the desired position in a relatively short period of time.

3) Drainage: Under periods of excess precipitation, adequate drainage is provided in a short period of time.

The smallest of the three calculated spacings should be selected because that spacing will more than adequately satisfy the other water management conditions.

Although subirrigation has been practised in Florida and North Carolina for over 30 years, it is a relatively new practice in Québec. Experiments have been conducted since the early 1980's in Richelieu and St-Hyacinthe counties in southern Québec, with promising results. A study by Papineau (1987) showed that there are 15 000 hectares of land suited to subirrigation in the above counties, and virtually none of this land is currently irrigated. This land is also well suited to the cultivation of soybean and corn.

Therefore there is considerable scope for the design and installation of subirrigation systems in Québec. However, water management engineers, drainage contractors, and farmers do not have the design criteria on the water table depth and drain spacing for maximum crop yields.

1.1 OBJECTIVES

The objectives of this research project were to:

1. Ascertain the effects of four water table levels on soybean grown in lysimeters in the field.

2. Determine the optimum water table for maximum potential yields of soybean.

3. The water management model, DRAINMOD, to derive water table management design criteria for some climatic and soil conditions in Quebec.

1.2 SCOPE

Although subirrigation is possible on many types of soil, with many different crops, this thesis is limited to the treatment of one soil type, a sandy loam, and one crop type, soybean. Due to the fact that the experimental plants are grown with much more space between plants than could be found in a field of soybean, large increases in yield are to be expected. Results from experimental plants should be considered as the maximum potential yield that can be obtained from the soybean plant. Relative yields between treatments should be applicable to large scale field cropping systems.

2.0 LITERATURE REVIEW

2.1 Soybean Physiology

2.1.1 Growth stages

There are many soybean cultivars, each with different characteristics. However, all have the same general growth stages. Fehr et al. (1971) were the first to propose such stages. There are 8 vegetative (V) and 8 reproductive (R) growth stages. Those of greatest significance include (V1) early development, (R1) beginning bloom, (R2) full bloom, (R1-R4) pod set, (R4-R6) bean production, (R5-R7) bean growth.

2.1.2 Planting date

Planting date is an important parameter in achieving good yields. The recommended planting date for the southern Quebec region is in mid-May. However, according to Scott and Aldrich (1983) there is little effect of small changes in planting date of up to about two weeks. Planting date is mainly influenced by soil moisture and temperature. The soil must be dry enough to allow the planting equipment on to the field without damage to the soil structure, but not so dry as to cause delays in germination due to lack of soil moisture. The soybean seed must reach a moisture content of 50% to germinate. A good supply of soil moisture is therefore essential.

For best germination results a threshold soil temperature of 10 Celsius must be achieved. Plant emergence occurs very slowly when the soil is cold. A seedling will emerge in 5 days to a week when the soil temperature is in the upper teens in degrees Celsius.

2.1.3 Development of the rooting system

The radicle is the first to penetrate the seedcoat and develops quickly into a root. Once this root is well established, the plant can push itself up through the soil. As the primary root elongates, lateral roots form, and root hairs appear within six days of germination. Within six weeks of planting, the roots will have extended to the centre of a 76 cm row spacing. The bulk of the root mass is comprised of lateral roots. Roots can reach a depth of 1.5 m in a well drained prairie soil. However, the bulk of root growth occurs in the top 30 cm of soil (Scott and Aldrich, 1983).

Water moves up from the water table to the plant roots by capillary rise. The amount of capillary rise is highly dependent on soil type, yet the soil water requirements of the crop does not vary. Therefore the desired water table depth must vary from location to location.

A study of water uptake by soybean roots was made at the Western Iowa Experimental farm, in Castana, Iowa, by Willat and Taylor (1977). The experiment was performed on an Ida silty loam soil. The purpose of this study was to obtain water extraction patterns of soybean, the total water use, as well as the effectiveness of water uptake of roots at various depths in the soil profile. It was found that the depth of water extracted by the root system increased with decreasing rooting depth. Water uptake rates decreased with soil water content at all soil depths. The soil water content at which roots extracted almost no water increased with water table depth. Lastly, the maximum rate of water uptake per unit length was greater for deep roots than for shallow roots.

From this experiment it can be seen that the deeper roots contribute to more water uptake than the shallow roots. This suggests that subirrigation of soybeans is feasible. When water is applied from the surface, it will not be taken up as efficiently by the shallow smaller roots. If the water is provided through subirrigation, the water uptake rate could be improved.

2.2 Water stress

Ashley (1983) and Van Doren and Reicosky (1987) have summarized relative soybean responses to water stress. Prior to beginning bloom (R1), soybeans are least sensitive to stress. Heavy lodging due to taller plants may result from excessive irrigation before full bloom (R2). Stress during bean production per pod (R4-R6) is most critical to yield due to pod and seed abortion. Kadhem *el al.*, (1985) concluded that the yield component response to irrigation was crucially influenced by irrigation timing during the temporal R1-R6 growth sequence.

2.3 Benefits of drainage

Soybean is a legume and, therefore, is capable of fixing nitrogen from the air with the aid of bacteria that live in nodules on the roots. For the bacteria to thrive, they cannot be waterlogged for extended periods of time, and hence good drainage is required for optimum growth. The necessity for good drainage as well as a need for irrigation suggests that water table control which provides both irrigation and drainage could be highly advantageous. Another important feature of the root system is the nitrogen-fixing bacteria which live in nodules on the roots. They supply most of the plants' nitrogen requirements. Minchen and Pate (1975), noted a drastic decline in N_2 fixation by rhizobia when other than optimum soil water content existed. The effect of low water potentials on N_2 fixation contributed to a reduced yield of the leguminous crop (Doss *et al.*, 1974). Mahler and Wollum (1981) examined the influence of Rhizobium japonicum strains on yields of soybean. At four weeks after planting, they noted that the leaves of soybean plants in the plots inoculated with strain 76 were exhibiting a yellow chlorosis. With certain soybean varieties, strain 76, a poor N_2 fixer, produced rhizobutoxin, a chlorophyll inhibiting toxin (Johnson and Clark, 1958; Owens, 1968). This chlorosis has been reported to occur often on sandy soils. However, soybean will eventually outgrow the symptoms (Johnson, 1958).

2.3.1 Effects of flooding

Prolonged flooding is harmful to most cultivated plants. It has been found to reduce plant growth and development. An experiment was performed (Sallam and Scott 1987) to evaluate the effects of prolonged flooding and soybean development especially during early growth stages. The soybeans were flooded with 2.5

cm of water for a 7 day period after seeding. It was found that flooding significantly reduced all soybean shoot and root development. Flooding at early growth stages completely inhibited nodulation on the soybean roots. The soybean therefore could not fix nitrogen from the air even after the water receded, which indicates a permanent damaging effect.

Flooding of soybean is dangerous. For this reason drainage of soybean fields is important. For subirrigation to be used, care must be taken when designing the system so that the overflow mechanism in the water control structures prevents rising of the water table above an allowable depth due to heavy rains. This is not a difficult task, but essential for subirrigation of soybean.

2.4 Response to irrigation

A wide range of suggested allowable water stress thresholds for optimal irrigation management exists in the literature. This range of allowable root zone depletions is 30 to 65% (Jones, 1983; Hearn and Constable, 1981; Brady, 1974). Stegman (1989) looked at relationships of relative yields to minimum available root zone water level. He concluded that the remaining available water levels should be maintained above 45 to 50% for maximum yield attainment.

Although soybeans show a general improved yield response to irrigation, the degree to which this occurs is not always consistent and is cultivar dependant. Camp, (1988) found that soybean response to irrigation was not as great, nor as consistent as corn response in a study of irrigation scheduling for the two crops. They suggested the lower response is due to the longer fruiting period of soybean, the greater drought resistance characteristics, and possibly a difference in photosynthetic capacity.

A study was performed on a Crowley silt loam soil, by Sojka *et al.*(1977). The treatments were frequent irrigation, irrigation at bloom, and non-irrigated. They found that irrigated plants showed an increase in height, dry weight and leaf area index. There was also a delay in the maturity of the irrigated beans of about one week. Yields of the non-irrigated and bloom irrigated beans varied only slightly, while the yield of the frequently irrigated beans was much higher. The increased yields were due to a greater number of beans rather than in any difference in bean size. Most soybean varieties have a potential of three seeds per pod, while some have the potential for four per pod. When the plants are stressed the pods will contain a decreased number of seeds, but the seeds that reach maturity are usually similar in size. This study showed that yields can be increased with frequent irrigation. If the method to be used was subirrigation, then the water is made available to the plant at all times, which is the best case of frequent irrigation. This suggests that subirrigation would be a good method for soybeans.

2.4.1 Stabilizing of yield using irrigation

Scott (1987) made a study of water use, seed yield and dry matter accumulation of Lee 74 soybean in a humid region. The experiment was with irrigated and non-irrigated soybean and was conducted over a period of five years. They used furrow irrigation to supply water. Significant differences between seed yields of irrigated and non-irrigated soybeans were observed in all years except the wettest year, where the planting date was delayed. The year to year variability of yield was 3.2 times higher in the non-irrigated treatment than in the irrigated treatment. This supports their conclusion that irrigation reduces the variability in seed yield.

2.4.2 Irrigation scheduling

The common belief is that irrigation should start when the available soil moisture in the root zone has fallen below 50%, after the plants have reached flowering period. Irrigation requirement is the amount of water that will supply the evapotranspiration needs of the plants. The water requirement can be supplied using flood or sprinkler irrigation as well as subirrigation, given the right conditions for each type of irrigation.

As soil moisture decreases during the season, the time to start irrigation is not well defined. With corn, a moisture stress near silking time will significantly reduce yields. With soybeans, the effect of moisture stress is a constant general stress, which reduces yield linearly (Scott and Aldrich 1983). Figure 2.1 shows the effects of moisture stress on soybean and corn.

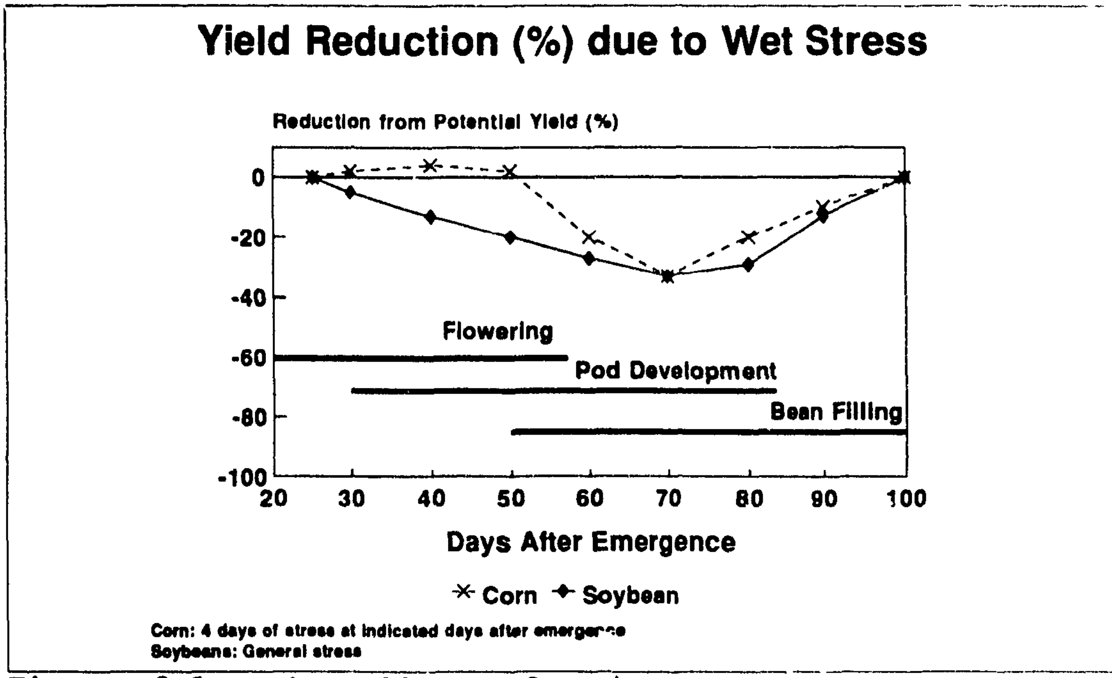

Figure 2.1 The effect of moisture stress on corn and soybeans related to stage of growth. (Adapted from Scott and Aldrich 1986.)

There is little need to irrigate soybeans before they bloom and start to set pods, provided that the subsoil moisture is fully recharged at a depth of 60 centimetres before planting. This condition is usually met in regions where soybeans are grown, due to the spring melting of snow. This statement can be supported by the findings of Matson (1964). He found that if irrigation was withheld until plants begin to bloom, and discontinued one month before harvest, yields were not greatly reduced. The problem is usually lowering the water table early enough to get on the field to perform seedbed preparation and planting. Subsurface drainage ensures that field machine trafficability is possible during the late Spring and Autumn.

2.5 Water table depth

Some information is available on the appropriate water table depth for corn in Québec, but there is little information for soybean. It was found that the water table depth that produced the highest soybean yield in a lysimeter experiment in North Carolina ranged between 0.45 and 0.60 m (van Schilfgaarde Williamson and , 1965). Galganov (1991) claimed that the minimum allowable water table depth for soybean is 45 cm, while at a water table depth of 95 cm no irrigation effect was observed.

2.6 The water table management model, DRAINMOD

DRAINMOD is a water management computer simulation model that was developed to simulate the performance of drainage and related water table management systems (Konya *et al.*, 1989). The program is written in Fortran and can run on any IBM compatible personal computer. A math co-processor is recommended to speed up the performance of the many mathematical calculations.

The model computes subsurface drainage rates, surface runoff and water table elevations based on actual historical climatic data. The climatic data that are used as inputs are daily rainfall and daily minimum and maximum temperatures. A water balance is conducted on a day to day basis. Trafficability and planting date are predicted and stress-day-index methods are used to calculate yield response to excessive and deficient soil water conditions (Skaggs and Konya, 1988). The daily PET values are calculated using the Thornthwaite method, if actual daily PET values are available they could be input to the model.

Several different output summaries of the simulations are available. It is possible to obtain outputs that are ranked, from highest to lowest values, or in chronological order. Outputs can either be obtained on a daily or monthly or annual basis. The performance of a given system can be tested over a long period of climatological data, 20 to 40 years for example, enabling the user to consider the effects of weather variability. For the purposes of this thesis outputs will be presented as yearly totals in chronological order in Appendix E.

2.6.1 Inputs to DRAINMOD

Input to the model include: climatic data, drainage design parameters, soil properties, and crop information. Rainfall and temperature files are used as inputs.

The drainage system parameters section of DRAINMOD input module lets the user define the type of drainage system to be tested. The drainage system design parameters include: depth, spacing and radius of lateral drains, depth to the restricting layer in the soil, the drainage coefficient, surface and soil moisture storage parameters, and weir settings for controlled drainage and subirrigation systems.

For most soils there is a restricting layer. This is a layer in the soil profile that has a significantly smaller conductivity than the layers above it. In the St. Lawrence valley, this layer is often made up of heavy clay. This layer is important, because without it would not be possible to maintain an artificially elevated water table.

Another important drainage design parameter is the drainage coefficient (DC in cm/day). The DC reflects the hydraulic capacity of the drains, or the design flow capacity. This is a function of the drain diameter and the slope of the installed drain.

When the program is run in subirrigation or controlled drainage modes, outlet weir settings can also be set. The program allows for one weir setting per month. The weir settings govern the height that the water level can be maintained within the soil profile. (Konya *et al*, 1989)

DRAINMOD soils data are very important for reliable simulations of system design and performance. The soil properties that are included as inputs to the model are as follows: hydraulic conductivity, soil-water characteristic curve, volume drained, upward flux, and Green Ampt equation parameters.

Model outputs are very sensitive to the saturated hydraulic conductivity, which is therefore an important input to the model. The soil-water characteristic is a measure of the water content in the soil at various tension levels. Values for this parameter can be obtained using a pressure plate apparatus. The volume drained is the volume of the soil profile that becomes air after the gravitational water has moved down to the water table. The program uses this relationship to determine the rise or fall of the water table when a given amount of soil water is removed or added. Upward flux is the rate of the water movement upward from the water table. This value is quite important since there may be insufficient water in the root zone to meet the PET needs of the crop. In these cases the upward flux into the root zone may limit PET and hence a dry day will occur.

For the Green-Ampt equation two coefficients, A and B, are required. Values for the coefficients are derived mathematically from the hydraulic conductivity and the soil water characteristic.

Crop inputs include trafficability section, crop rooting depth, general crop, crop relative yield, and planting delay. For each of these topics one or several values are input to the program.

2.6.2 Outputs from DRAINMOD

DRAINMOD has many possible outputs, that can be presented in different ways. The output parameters that tabulated are, stress day index, planting date, planting delay, harvest date, and relative yields. Also shown are simulated water table elevations for three selected years of climatic conditions and water table management methods. These water table elevations are shown in Figures 4.13 to 4.18.

The most important output that will be considered is that of relative yield. The relative yield is made up of three components, reductions due to wet and dry stress and delays. They are expressed as percentages of the optimal yield attainable. To find the total relative yield the three factors are multiplied together.

2.7 Summary

It has been concluded (Sipp *et al.* 1986) that both drainage and irrigation individually increased yields and that a positive synergetic effect of the combination of drainage and irrigation is present. This conclusion was reached after experimentation on claypan soils. It was also concluded that the method of irrigation had little effect on yield.

An economical way to combine irrigation and drainage is to use a water table management system, which is a system of subsurface perforated tubing designed to provide both drainage and irrigation for a given area. This method of water table control is ideal when both drainage and irrigation are required to produce a good crop. Although these conclusions were arrived at using a claypan soil, they can be applied to some other soils as well, if the different conditions are considered carefully. At this time little is known about the effectiveness of subirrigation of claypan soils. It is known that subirrigation works well on sandy soils.

In the past, much research has been done on subirrigation of corn, with an average yield increase of 29% in Richelieu County, Québec, Canada over a six year study period from 1982 to

1988 (Drouet, 1989), and 20 to 100% in the sandy soils in the Lowlands of Southern Québec, Canada (von Hoyningen Huene et al., 1985). In another study, over three growing seasons 1988 to 1990 in Richelieu County, yield increases of 28% were found for soybean (Galganov, 1991). Now there is interest in controlled drainage and subsurface irrigation of soybean, to improve yields and profit potential.

The important factor that is missing for the design and implementation of subirrigation systems, is at what depth should the water table be maintained to provide best results from year to year. This is the purpose and focus of the research conducted, and reported in this thesis.

3.0 Materials and Methods

The effects of four water table depths on soybean growth were tested. The four water table treatments were 0.4, 0.6, 0.8 and 1.0 meter in depth from the soil surface. The 1.0 m treatment was considered as a conventional drainage case. The experiment was conducted during the 1989 and 1990 growing seasons. The experimental site was located at the Horticultural Research Station at the Macdonald Campus of McGill University, in Ste. Anne de Bellevue, Quebec.

3.1 Lysimeter Construction

Lysimeters were constructed from double wall polyethylene (PE) pipe, 480 mm in diameter and 1.2 meters deep, sealed at the bottom with concrete. A schematic of a lysimeter is shown in Figure 3.1. The lysimeters were installed in an excavated area, connections were made to the water level control chambers for water supply, and then soil was carefully backfilled around the lysimeters.

The tops of the lysimeters extended 0.1 m above the soil surface to prevent surface water running into the lysimeters, as well as to retain all rainwater that fell within the lysimeter. The lysimeters were supplied with water from the water level control chambers by 40 mm diameter non-perforated polyethylene tubing. This tubing was then connected to a length of the same tubing, inside each of the lysimeters, that had been perforated and covered with a filter sock. This perforated tubing simulated a subsurface drain lateral pipe for water supply.

3.2 Description of Water Level Control Chambers

The water level control chambers were made from the same material as the lysimeters, and were buried in the soil to the same depth. A schematic of a water table control chamber can be seen in Figure 3.2. The control chambers were equipped with a water supply pipe to the lysimeters, as well as a variable height overflow pipe to control the water table depth.

A hydraulic head system for maintaining a constant water level in each chamber was also developed. It was fashioned after a Marriotte bottle apparatus. It proved to be effective in regulating the water level in the water level control chambers, when water had to be added.

The water level control chambers were of the same diameter as the lysimeters. Therefore the average volume of water delivered to each lysimeter would be the amount delivered to the corresponding control chamber divided by the number of lysimeters that it supplied.

3.3 Water Table Observations

In order to observe the water table depth in each lysimeter, the technique of Broughton (1972) was followed. In each lysimeter a 19 mm by 1.2 m long PVC water table pipe was installed. This pipe was sealed at the bottom, perforated with 6 mm diameter

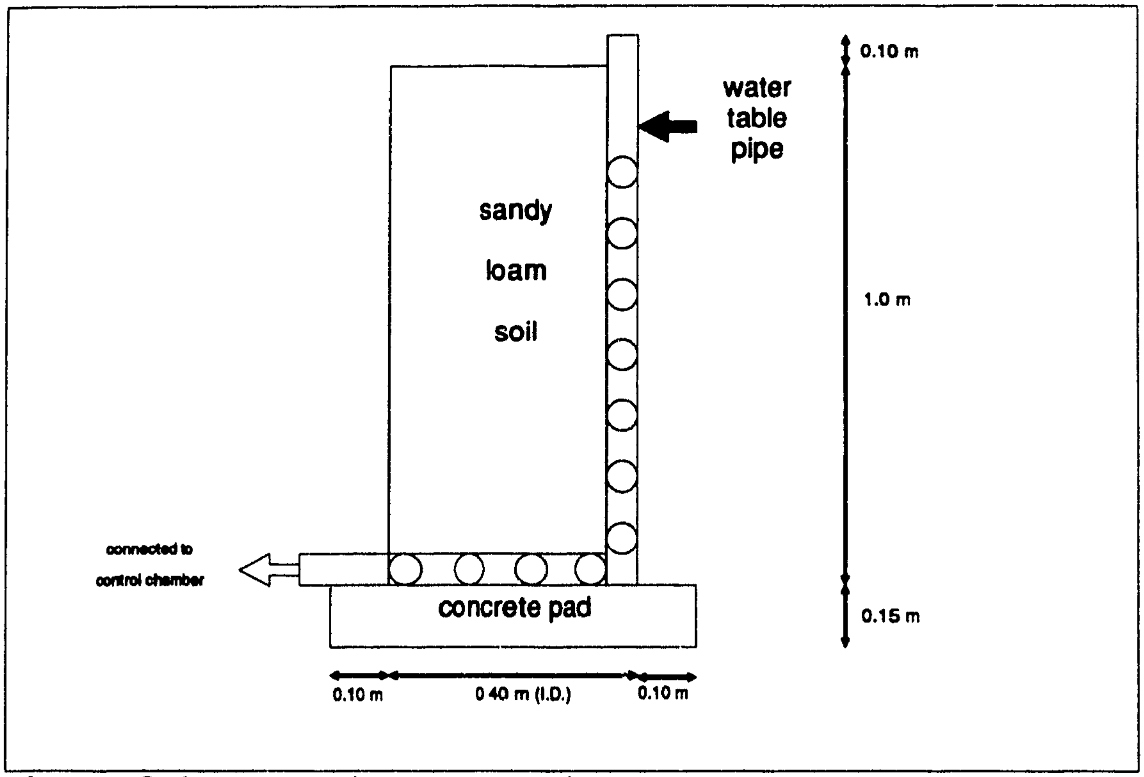

Figure 3.1 Schematic of a lysimeter.

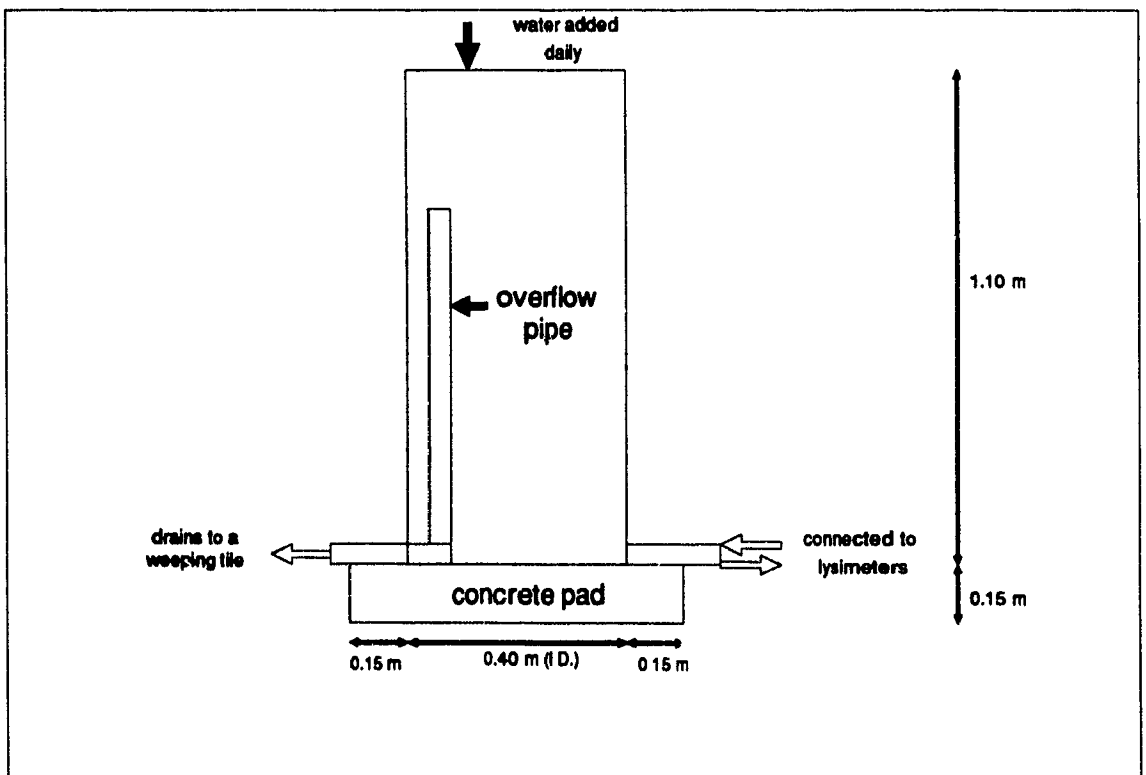

Figure 3.2 Schematic of a water table control chamber.

holes at 75 mm intervals along its length, and wrapped with filter material to inhibit the entry of fine soil particles. A water table sensor was introduced into an observation well to provide a measurement of the location of the water table in each lysimeter.

To establish the water table elevation for each lysimeter and water level control chamber a topographic survey was made of the tops of the water table pipes in each lysimeter, and the tops of each water level control chamber. From this information it was possible to evaluate the water elevations in the control chambers.

Water table readings were taken, in each lysimeter, on a daily basis for the first two weeks of each experimental year. These readings were used to establish the necessary water level in each of the control chamber that would correspond to the desired water table elevations for each of the treatments. Once the control chamber water table levels were established, they were measured and adjusted on a daily basis. The levels in all of the lysimeters were then only measured twice monthly.

3.4 Layout of lysimeters

The lysimeters were divided into four groups of twenty. Each group had four water table control chambers, and five rows of four lysimeters. Individual lysimeters within each group were assigned an address of a letter and a number in a grid system. The layout can be seen in Figure 3.3. Five lysimeters in each group were randomly connected to each control chamber,

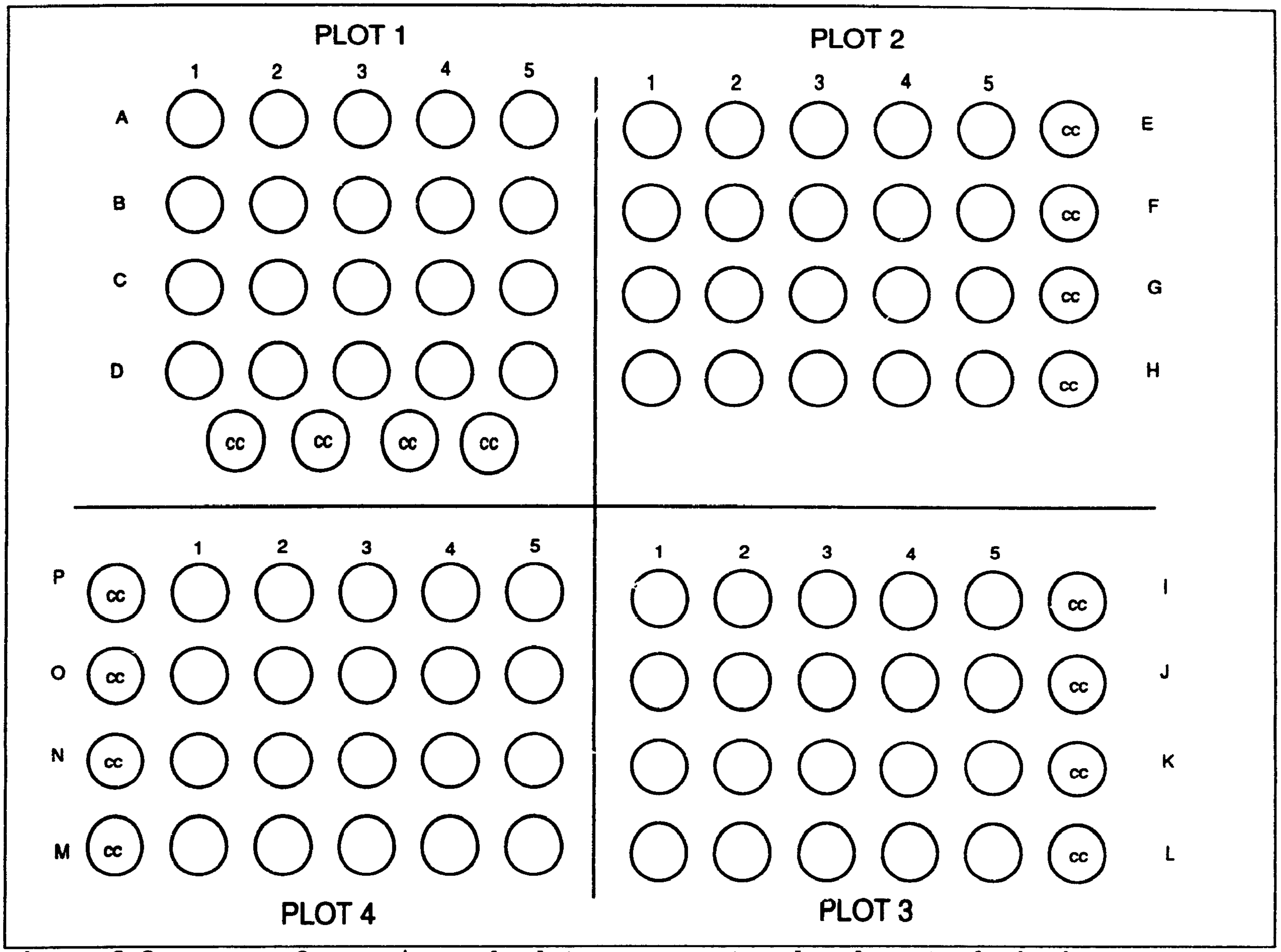

Figure 3.3 Layout of experimental plot. cc - water level control chamber

using 30 mm PE water pipe. The size of the experiment was increased, from 20 lysimeters in the 1989 growing season to 80 lysimeters in the 1990 growing season, in order to provide a greater precision for the experimental results.

3.5 Agronomic Practices

Five soybean plants of the Apache variety were planted in each lysimeter on May 25, 1989. On June 16, 1989, the number of plants in each lysimeter was thinned to the two healthiest. Soybean plants were grown between the lysimeters, as well as on a 1 m wide strip around the perimeter of the plots to negate edge and island effects. Weeding was done by hand and no herbicides were applied during the growing season. The experimental plot was initially sprinkler irrigated to ensure seed germination. The four water table treatments were started on June 12, 1989, and were maintained until September 10, 1989, when the lysimeters were drained to allow the plants to dry in preparation for harvest. The soybeans were harvested by hand on October 15, 1989. There were no fertilizers applied.

Similar agronomic procedures were followed in the 1990 growing season. However, certain changes were made to the experimental setup. The number of lysimeters was increased from 20 to 80. Two varieties of soybean were tested, Apache a large seeded variety, and KG30 a small seeded variety. Apache was tested on plots 1 and 2, and KG30 was tested on plots 3 and 4, shown in Figure 3.3. Initially, five seeds were planted in each lysimeter on May 15. The number of plants in each lysimeter was then reduced to one, on June 5, 1990, to eliminate excessive plant competition within individual lysimeters. No sprinkler irrigation was applied, because there was sufficient rainfall to ensure proper germination of the soybean plants. The water table treatments were started on June 1, 1990, and were maintained until September 10, 1990, when the lysimeters were drained to allow the plants to dry in preparation for harvest. The soybeans were harvested by hand on October 15, 1990.

3.6 Plant measurements

The following plant parameters were measured in 1989: seed mass per plant, number of seeds per plant, number of pods per plant, moisture content of beans at harvest, and crude protein and oil content of beans at harvest. Total nitrogen was analyzed by the Kjeldhal sulphuric acid digestion and steam distillation method. The total nitrogen value was then multiplied by 6.25 to give the crude protein content. Measurements were taken for all plants in all lysimeters in both growing seasons. In 1989 this resulted in 40 samples, (20 lysimeters * 2 plants per lysimeter), while in 1990 there were 80 samples (80 lysimeters * 1 plant per lysimeter). In 1990, in addition to the above parameters, the combined length of the main stem and all the secondary branches was also measured.

3.7 Soil physical properties

The soil used in this experiment was taken from a Courval sandy loam profile. The soil was repacked in each lysimeter in 0.15 m increments and tamped to a bulk density of approximately

$1.1\ g/cm^3$.

The soil particle size was analyzed using the hydrometer method. The results show that the soil was composed of 85% sand and 15% clay, which is classified as sandy loam.

3.8 Weather Observations

Rainfall, pan evaporation, wind run, minimum and maximum temperatures in the evaporation pan, and minimum and maximum air temperatures were measured daily for two growing seasons at the nearby Brace Research Field Station. These climatological data are shown in Appendix F.

3.9 DRAINMOD Simulations

DRAINMOD was used to simulate the effects of three different water table management scenarios on relative soybean yields for a range of climatic conditions. The water table management scenarios were, conventional drainage, controlled drainage and subirrigation. The controlled drainage and subirrigation cases were each tested with three weir settings, 40, 60 and 80 cm, which correspond to the levels tested in the field lysimeter study. For all simulations the drain spacing was kept at 20 m. This spacing was found to give good drainage as well as being able to control the elevated water table in the subirrigation mode. The only parameters that were varied from simulation to simulation were the weir settings, and the water table management scenarios. Some of the input parameters used for the simulations can be seen in Table 3.1. For the controlled drainage and subirrigation cases, three weir settings were tested, 40, 60 and 80 cm, which correspond to the water table treatments evaluated in the field lysimeter experiment. The conventional drainage case is similar to that of the 100 cm water table depth tested in the lysimeter experiment.

Table 3.1 Some DRAINMOD input parameters and their values.

Parameter	Value
Drain Spacing	2000 cm
Drain Depth	100 cm
Depth to impermeable layer	110 cm
Drainage coefficient	1.0 cm/day
Hydraulic conductivity	9.5 cm/hr
Wilting point water content	0.30
Surface Storage	1.5 cm
Maximum Rooting Depth	30 cm

The weather data that were used for all simulations was from Dorval International Airport. Twenty-four years of daily rainfall and temperature, from 1960 to 1983, were used in DRAINMOD simulations, as well as in comparisons for the data obtained in the two experimental years. The once in 24 driest and wettest years were found, as well as a year that received close to the average amount of precipitation from the 24 years. These years are 1971 driest, 1961 the average, and 1972 wettest.

The simulations were performed to assess the water table management practice and weir setting for maximum relative crop yield. These simulations are useful because the effects of widely varying climatic conditions and water table management practices can be rapidly and inexpensively evaluated. This is not possible under field conditions because many years of field experimentation and data collection would need to be conducted. The results from these simulations can show what management practices give the highest relative yields, and therefore the best financial return to the growers.

Some input parameters were found experimentally, such as the water retention data, and hydraulic conductivity. Climatic data were obtained from the Dorval International Airport. Some soil trafficability data were taken from Madramootoo (1990), Drablos *et al.* (1988), and Baumer and Rice (1988). For a sample output of a simulation run, and input parameters see Appendix E.

4.0 RESULTS AND DISCUSSION

4.1 Climatic Data

Monthly crop evapotranspiration (ET) was found by multiplying the pan evaporation by a pan constant (*kp*) and a crop consumptive use constant (*kc*). The pan constant is a function of the amount of wind run on a given day, while the crop consumptive use constant is a function of the time of the growing season. The value used for *kp* was 0.65. For *kc* there is a value for each of the five crop development stages shown in Table 4.1.

$$ET = kp * kc$$

Table 4.1 Crop consumptive use coefficients.

Crop Growth Stage	Crop Consumptive Use Coefficient (*kc*)[1]
Initial	0.35
Development	0.75
Mid-season	1.10
Late season	0.75
At harvest	0.45

[1]The values for *kp* and *kc* were taken from FAO 1977.

Table 4.2 shows the growing season rainfall measured at the experimental site, and a long term average of the years 1960 to 1983 measured at the Dorval International Airport. The monthly rainfall, pan evaporation, and crop ET for the 1989 and 1990 growing seasons are shown in Tables 4.3 and 4.4 respectively.

Table 4.2 **Monthly rainfall for 1989 and 1990 growing seasons and long term monthly average.**

	1989	1990	1960 to 1983[1]	
Month	Rainfall (mm)	Rainfall (mm)	Rainfall (mm)	Stand. Dev. (mm)
June	*	140.1	71.5	33.0
July	45.8	112.1	78.8	39.0
August	77.4	94.6	85.8	37.4
September	56.2	77.1	84.4	45.7
TOTALS	179.4	423.9	320.5	76.5

[1] Measured at Dorval International Airport.
* Full month data were not available.

As can be seen from Table 4.2, for the 1989 growing season there was less rainfall, in each month, than the long term average. The data in Table 4.3 show less rainfall than ET in all months. This suggests a need for supplemental irrigation during the 1989 growing season. The negative signs in the last column of Table 4.3 represent the depth of water needed to fulfil the ET requirements of the crop.

Table 4.3 **Rainfall and Evapotranspiration (ET) data for the 1989 growing season.**

	1989			
Month	Rainfall (mm)	Pan Evaporation (mm)	ET (mm)	Rainfall - ET (mm)
June	*	*	*	*
July	45.8	177.3	119.2	-81.0
August	77.4	138.4	83.4	-26.1
Sept.	56.2	78.4	28.4	- 0.1
TOTALS	179.4	394.1	231.0	-107.2

* Full month data were not available

In 1990, as is shown in Table 4.2, the rainfall was greater than the long term average value for three of the four months of the growing season. In Table 4.2 the September 1990 rainfall value was lower than the long term average, however this month has a much lower ET requirement. As can be seen from Table 4.4, in all months, the crop ET requirements were exceeded. This information suggests little need for supplemental irrigation during the 1990 growing season.

Table 4.4 Rainfall and Evapotranspiration data for the 1990 growing season.

	1990			
Month	Rainfall (mm)	Pan Evaporation (mm)	ET (mm)	Rainfall - ET (mm)
June	140.1	153.1	55.9	84.2
July	112.1	179.5	107.2	4.9
August	94.6	149.5	89.7	4.9
Sept.	77.1	85.6	30.3	46.8
TOTALS	423.9	567.7	283.1	140.8

4.2 Results of Crop Measurements for 1989

In 1989, Apache variety soybean plants were grown in 20 lysimeters with two plants per lysimeter. Figures 4.1 to 4.4 show plant measurement data collected from the 1989 growing season. Four different parameters are shown as a function of water table depth. They are: seed mass per plant, number of seeds per plant and number of pods per plant. On each graph, a scatter of points is shown. Each point represents the value measured from a single plant. Also on each graph is a line that joins the means of each treatment. All the data that is shown in the graphs can also be found in tabular form in Appendix A.

In Figure 4.1, the trend of the means suggest a decrease in seed mass with increasing water table depth. The highest average mass of seeds per plant was 38.90 g, while the lowest was 34.59 g, for water table depths of 40 and 100 cm, respectively.

In Figures 4.2 and 4.3, number of seeds, and number of pods show a maximum at a water table depth of 80 cm. This follows, since an increase in the number of pods would also increase the total number of seeds per plant. Average number of seeds per pod (Figure 4.4), shows a decrease at the 80 cm water table depth. This information agrees with the increase in number of seeds because, the increase in number of pods is sufficient to compensate for the decrease in number of seeds per pod.

Plant data was highly variable within treatments in the 1989 growing season, both between plants in the same experimental unit and between plants in different experimental units, of the same water table treatment. This could be due to several factors. One of the largest factors is the plant population density. In 1989, the plant population density was 2 plants per lysimeter. In the first year of experimentation there were only 20 lysimeters at the test site, and in an effort to increase the number of sampling units, two plants were grown per lysimeter. The soybean plant is very sensitive to plant spacing (Galganov 1991). The soybean is very adaptable and capable of filling all available space. Therefore, if two plants are close to one another, they will be smaller than two plants that had more space between them. Plant spacing between plants in different lysimeters was not equal. This is because five seeds were planted in each lysimeter to ensure that after germination there would be at least two healthy plants in each lysimeter. When plants were thinned to two plants per lysimeter, it was difficult to obtain a uniform spacing. For these reasons plant spacings varied, and as a result the yields measured were highly variable.

Another problem that was encountered in 1989, was the presence of Atrazine and its metabolites in the soil placed in the lysimeters. Atrazine is a herbicide used in corn production. The soil that was used for the experiment was taken from a field that had grown corn the year before, and there were still traces of the herbicide in the soil. The problem was discovered when leaves on most plants turned yellow and brown. According to Scott and Aldrich (1983), these symptoms suggest either problems caused by herbicide, or lack of micronutrients. Soil samples were taken from the lysimeters, and analyzed for herbicides. The analysis showed that Atrazine and its metabolites were present in sufficient quantities to harm the plants. As a precaution, seaweed fertilizer, that is very high in micronutrients was generously added to the soil in all treatments. According to Scott and Aldrich (1983), soybean tends to grow out of the condition. The plants seemed to recover, but they did not reach their full potential. Later there were some losses of plants to neighbouring marmots. They were controlled through live traps and an electric fence surrounding the experimental site. All these conditions contributed to the variability of the harvest data. Soybean is a self-pollinating species, thus theoretically all plants of a variety are the same genotype. Therefore, one would expect to plants within a cultivar to perform similarly.

Coefficients of variability (CV) within treatments varied between 47% and 61% for total seed mass, number of seeds, and number of pods. The CV for number of seeds per pod was about 13% and for protein content between 4.7 % and 8.7%. The results are presented in tabular form in Appendix A.

The water table did not significantly increase yields in the 1989 growing season. This is, in part, due to the high variability in data that was observed. However, the trends of the means do suggest that a maximum yield is obtained with a water table depth of about 80 cm.

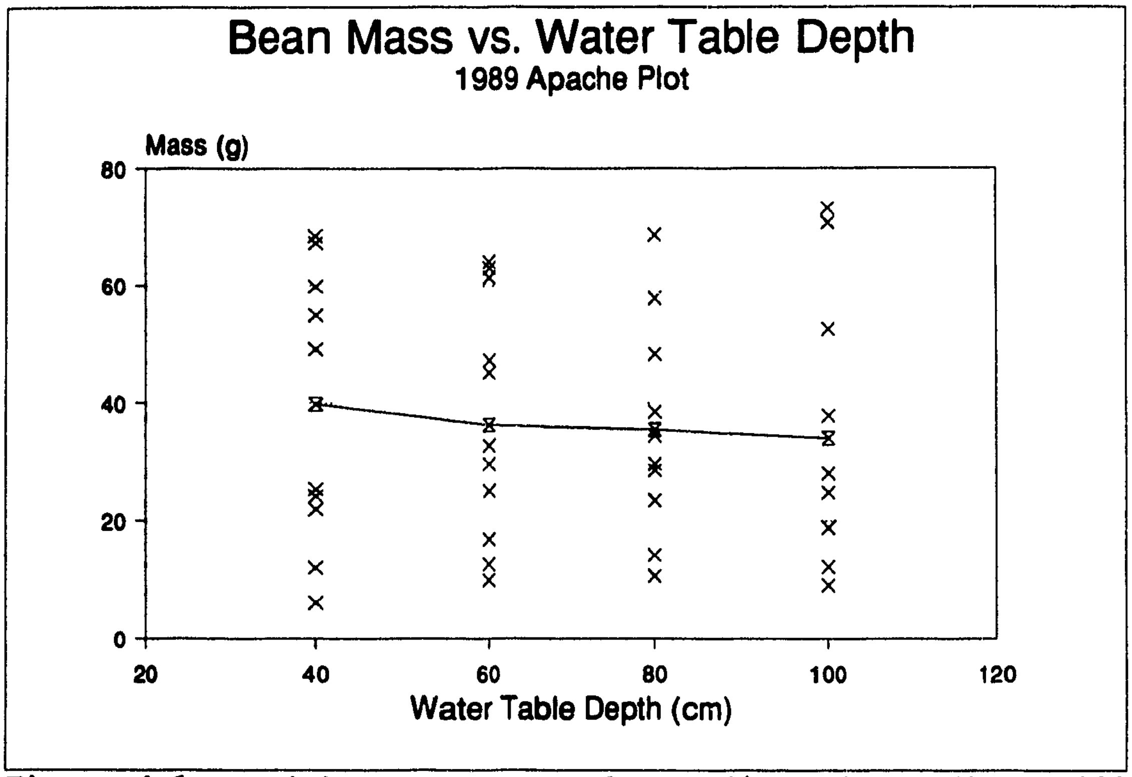

Figure 4.1 Total bean mass per plant adjusted to 14% MC 1989 Apache Plot.

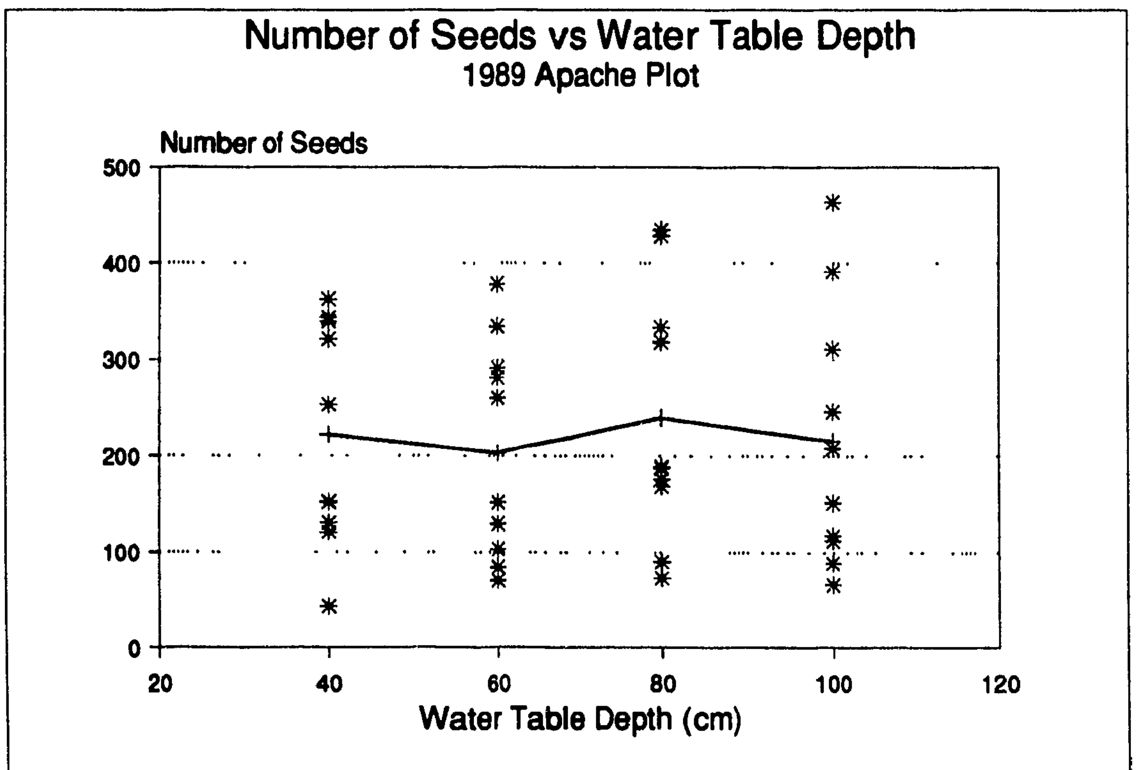

Figure 4.2 Total number of seeds per plant 1989 Apache plot.

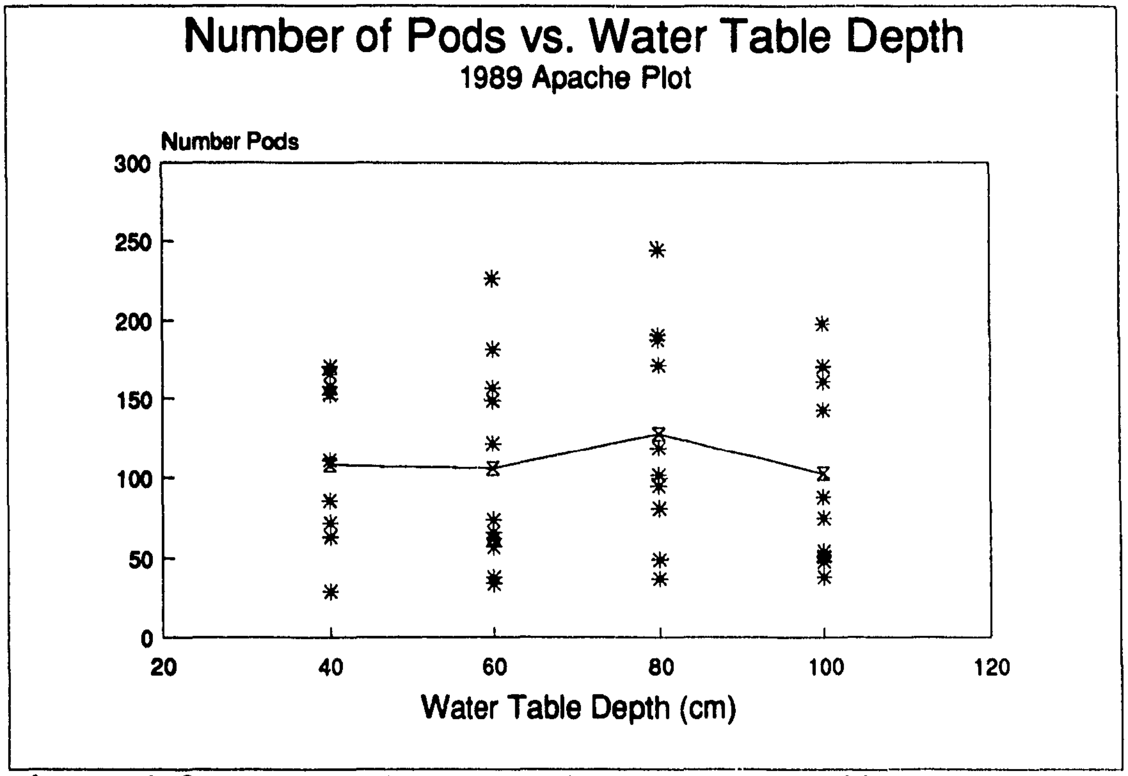

Figure 4.3 Total number of pods per plant 1989 Apache plot.

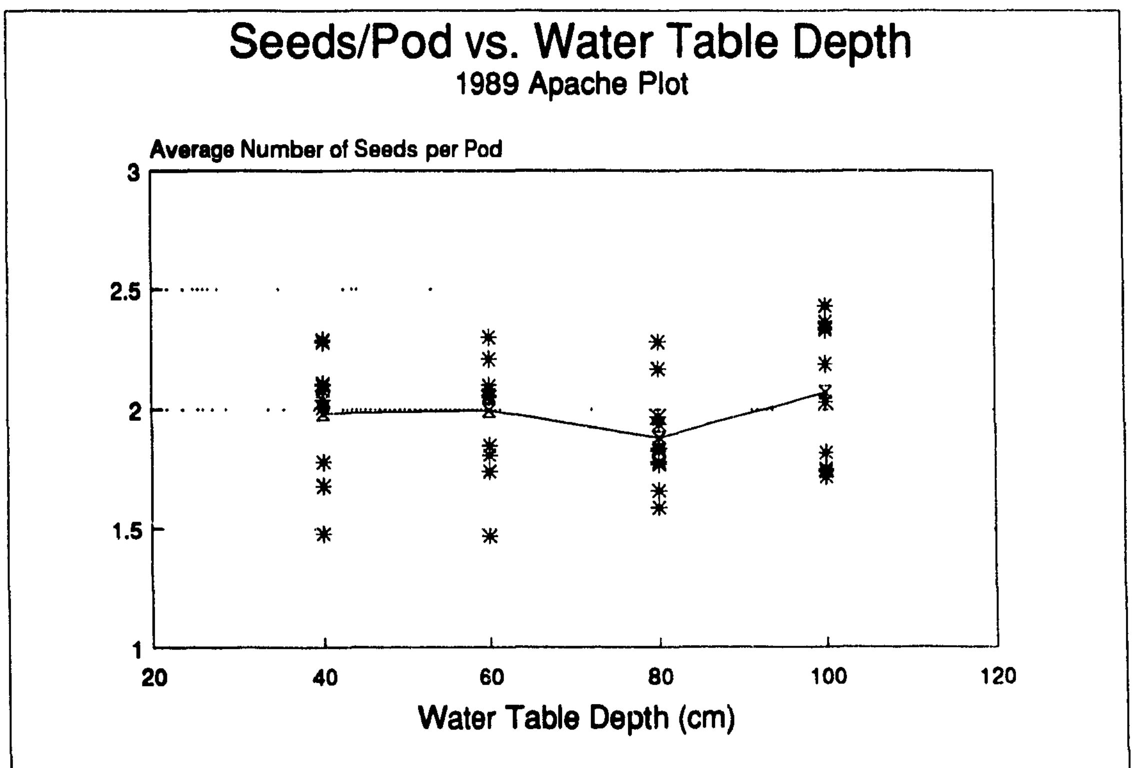

Figure 4.4 Average number of seeds per pod 1989 Apache plot.

4.3 Changes in the experimental setup in 1990

In the 1990 growing season, a few important changes were made to the experiment. One of these changes was to grow two varieties of soybeans in an attempt to see whether there was a greater response by Apache (a large seeded variety) or KG30 (a small seeded variety) to water table depth. The number of lysimeters was increased to 80, one half was used to grow Apache, while the other half was used to grow KG30. This greater number of lysimeters not only provided much more data, but also enabled the number of plants per lysimeter to be reduced to one, thereby reducing variation due to plant population. There were no problems with plant growth, or damage by rodents. The water supply was steady and the water table treatments maintained for the entire growing season. Rainfall provided sufficient moisture, in every month of the growing season, to satisfy the evapotranspiration requirements, thereby reducing the need for supplemental irrigation.

The subirrigation system with well designed overflows still improved crop yields. The water management system provided a good soil moisture condition throughout the growing season. In rainy years the system acts more as a controlled drainage system. It holds moisture provided by rainfall and irrigation within the soil profile, which is then used by the plants in times of lower rainfall. At the same time the water table management system ensures that the plant roots do not remain waterlogged for extended periods, which is harmful to soybean.

4.4 1990 Crop Data Results

4.4.1 Apache Variety Results

In the 1990 growing season the Apache variety of soybean was grown in the plots 1 and 2 shown in Figure 3.4.

In Figures 4.5, 4.6, 4.7, and 4.8, the line that joins the means has a maximum corresponding to a water table depth of 80 cm. As can be seen from the scatter of data points in these graphs, the variation is smaller for the 80 and 100 cm water table depths, with the exception of one very low data point in the 80 cm water table treatment. Reduced scatter indicates that the plants are growing in a favourable soil moisture and aeration condition. The CV's are smaller at the 100 cm depth than at the 80 cm depth, but this order would be reversed, if the lowest data point in the 80 cm treatment was removed. The highest average for seed mass was 77.62 g and number of seeds per plant was 434. These results suggest that the best water table depth for Apache soybean is near 80 cm. This also agrees with what was seen in the 1989 growing season, where the maximum numbers of seeds and pods occurred at the 80 cm water table depth.

In Table 4.5, each protein content value is the combined value from five plants per experimental plot. Apache variety was grown in plots 1 and 2, while KG30 variety was grown in plots 3 and 4. For plot locations, please see Figure 3.3. The highest values for both varieties were found at a water table depth of 60 cm, although the treatment averages did not prove to be significantly different.

Table 4.5 Effects of water table depth on Protein Content (%) during 1990.

	WATER TABLE TREATMENTS (cm)			
Location	40	60	80	100
[1] Plot 1	44.63	43.69	43.44	39.19
[1] Plot 2	35.88	45.19	42.88	44.63
[2] Plot 3	33.63	40.81	35.75	34.06
[2] Plot 4	45.22	40.94	37.50	42.06
AVERAGES	39.84	42.66	39.89	39.98
STD	5.96	2.15	3.84	4.53
CV%	14.95	5.03	9.64	11.33

Locations refer to grid found in Figure 3.3.
[1] Data from 1990 Apache plots
[2] Data from 1990 KG30 plots

Figures 4.5 to 4.8 show data collected from the 1990 Apache plots, while Figures 4.9 to 4.12 show data collected from the 1990 KG30 plots. For each soybean variety four different parameters are shown as function of water table depth, they are: seed mass per plant, number of seeds per plant and number of pods per plant. On each graph a scatter of points is shown. Each point represents the value measured from a single plant. Also on each graph is a line that joins the means of each treatment. All the data that is shown in the graphs can also be found in tabular form in appendix B and C for the Apache and KG30 varieties respectively.

The variations of all parameters measured, within treatments was lower than was found in the previous year.

Coefficients of variability (CV) within treatments varied from 25% to 39% for total seed mass, 21% to 34% for number of seeds, and 18% to 27% for number of pods. The CV for number of seeds per pod was between 5% and 17% and for protein content between 5% and 15%. A parameter considered in the 1990 season was that of total branch length, which was the sum of the lengths of the main stem plus all the branches. The very low plant population enabled all plants to have many branches, up to 8 or 9. This amount of branching would suggest that there would be more room for a greater number of pods, and hence a greater number of seeds. This was not the case. The plants that grew under the shallowest water table conditions, 40 and 60 cm in depth, had fewer seeds on average, while producing a longer total branch length.

Soybean has two major growth stages, vegetative and reproductive. The soybean varieties that are grown in Quebec are indeterminate types, which means that the plant still increases in height after the onset of flowering and pod setting. For the plants to continue growing in height, more moisture is required, which is the reason that the shallower water table produced longer total branch length. At the same time there were fewer seeds on these plants due to high moisture conditions, which favour vegetative growth.

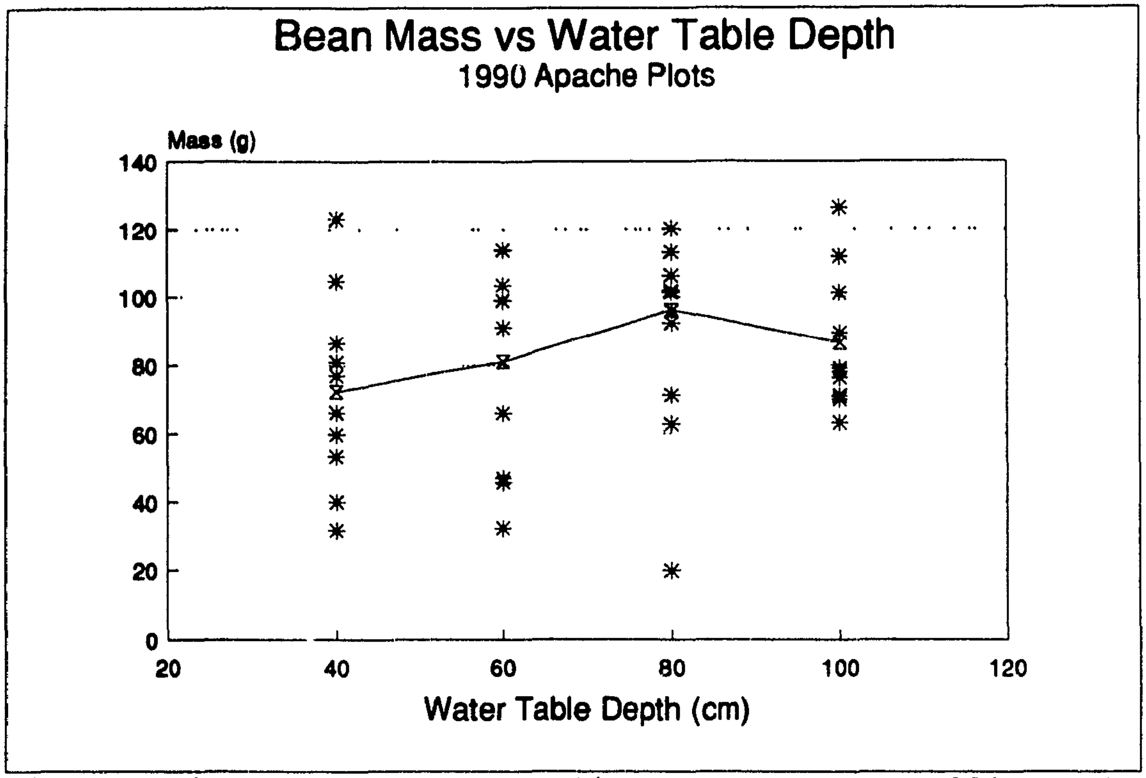

Figure 4.5 Total seed mass adjusted to 14% MC 1990 Apache plot.

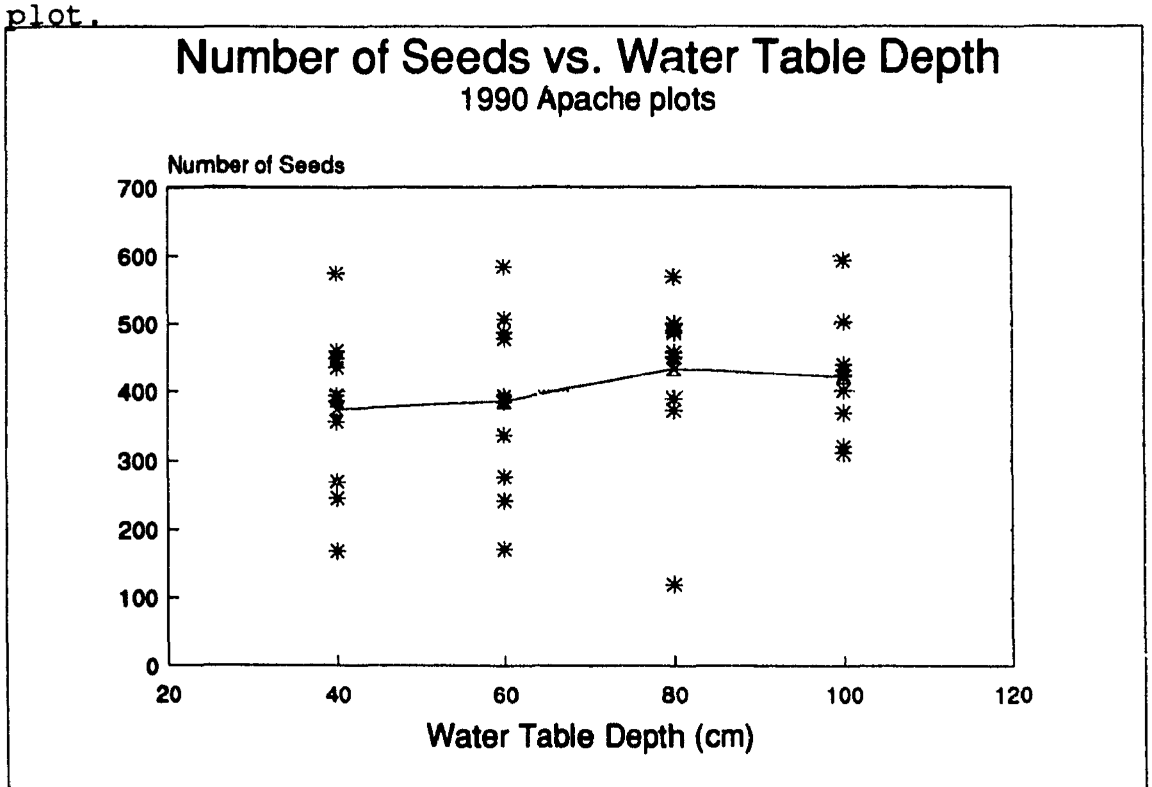

Figure 4.6 Total number of seeds per plant 1990 Apache plot.

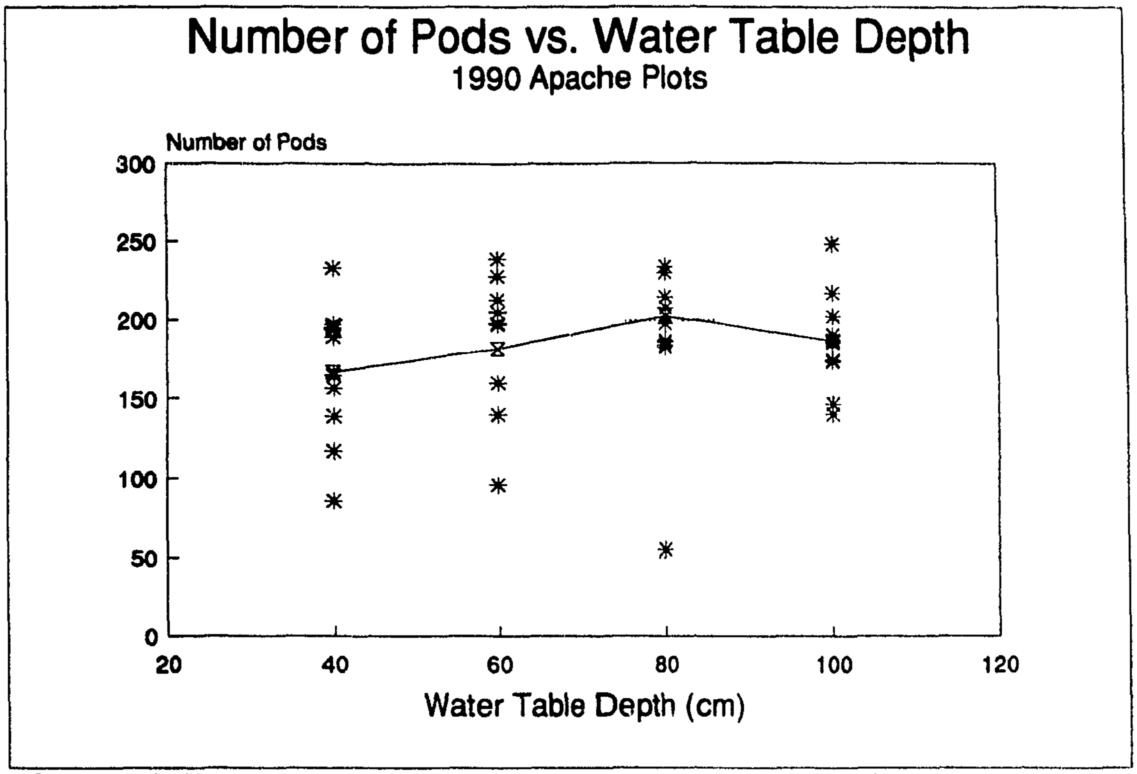

Figure 4.7 Total number of pods per plant 1990 Apache plot.

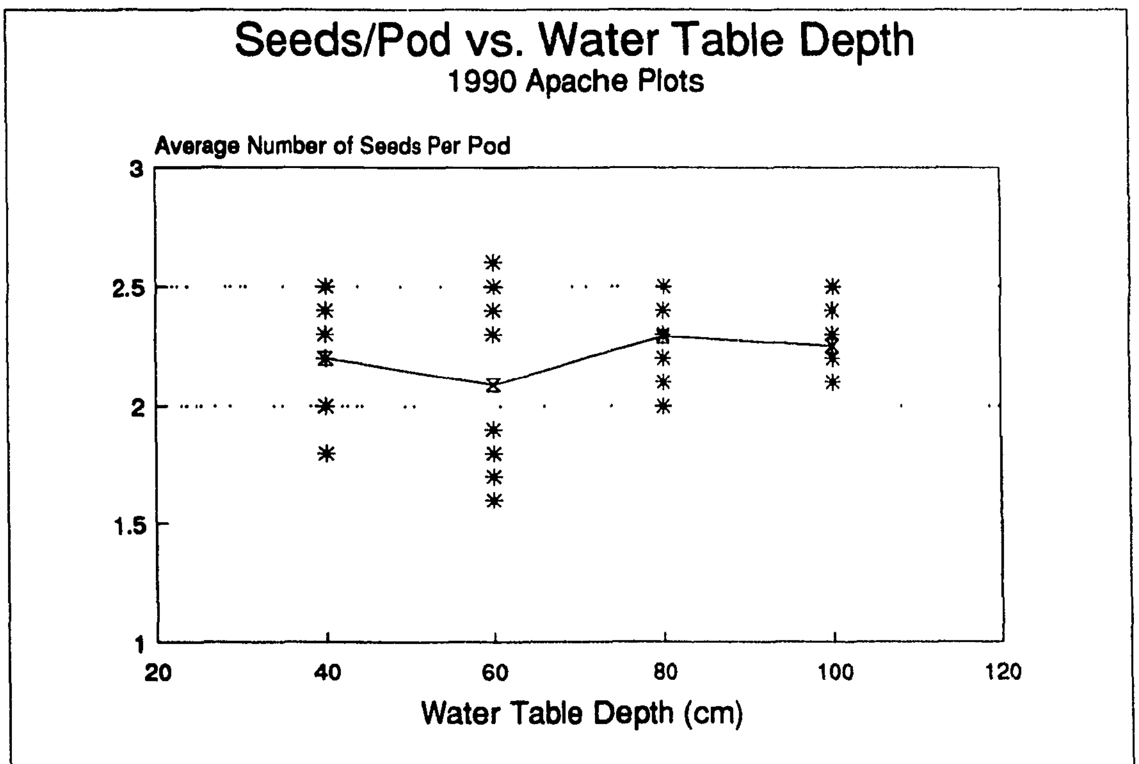

Figure 4.8 Average number of seeds per pod 1990 Apache Plot.

4.4.2 KG30 Variety Results

In the 1990 growing season the KG30 variety was grown in plots 3 and 4 as shown in Figure 3.3.

The trend from the Apache soybeans for the shallow water table depths to produce the greatest total branch length was also apparent with the KG30 variety, for similar reasons. Although with KG30 the greatest number of seeds and pods was found the 60 and 80 cm water table depth treatments.

In Figures 4.9, to 4.11, the lines that join the means of the parameters all have a similar shape. The line that joins the means of the 60 and 80 cm depth form a line with near zero slope, while the slope of the lines that join the means of the shallowest and deepest treatments are much steeper. The slopes of the lines show that there is little change in the measured parameters in the 60 to 80 cm water table range, while there is a rapid decrease in the values obtained from the shallowest and deepest water table treatments. This suggests that a water table depth between 60 and 80 cm in depth produces highest crop yields.

The highest averages for seed mass was 61.13 g at a water table treatment of 60 cm and 57.15 g at a water table treatment of 80 cm. There were 444 seeds per plant at a water table treatment of 60 cm, and 453 seeds per plant at a water table treatment of 80 cm. The average total mass of seeds per plant was lower than that of the 1990 Apache trial, but not significantly. Although the protein content, shown in Table

4.5, is highest at a water table depth of 60 cm, it is not significantly different from the results found in the other treatments.

Coefficients of variability (CV) within treatments varied from 39% to 66% for total seed mass, 35% to 65% for number of seeds, and 34% to 59% for number of pods. These variabilities were higher than found for the Apache variety in the same growing season. As was previously mentioned, the difference between means of all parameters at the 60 and 80 cm water table treatment was not statistically different. This trend is also true for the CV's for the same depths. The CV's of the deepest and shallowest water table depth were similar and substantially higher than those CV's at the other two water table depths. This suggests that the best soil moisture condition is found in the water table range of 60 to 80 cm in depth. The CV for number of seeds per pod was between 5% and 11% and for protein content, as shown in Table 4.5, between 5% and 15%.

The 1990 growing season had higher than average rainfall. For this reason, the need for irrigation was not significant. For both varieties, Apache and KG30, the trend of the means showed that the best water table depth for maximum yields is between 60 and 80 cm in depth.

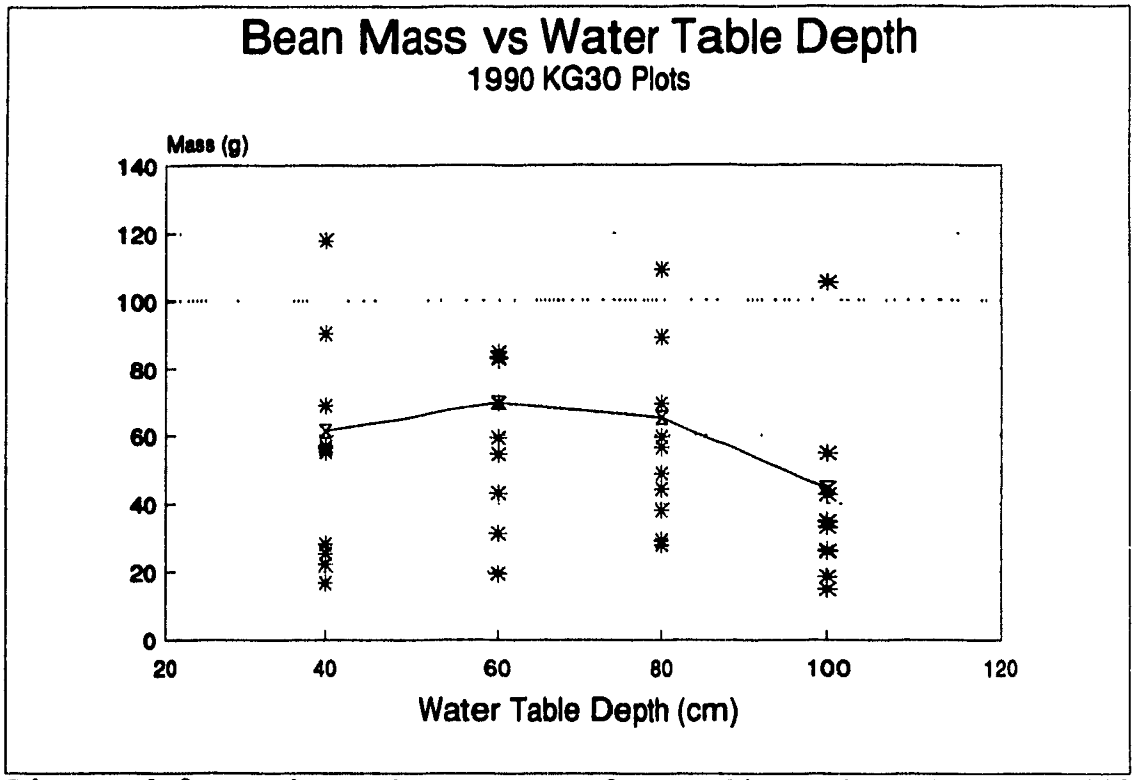

Figure 4.9 Total seed mass per plant adjusted to 14% MC 1990 KG30 plot.

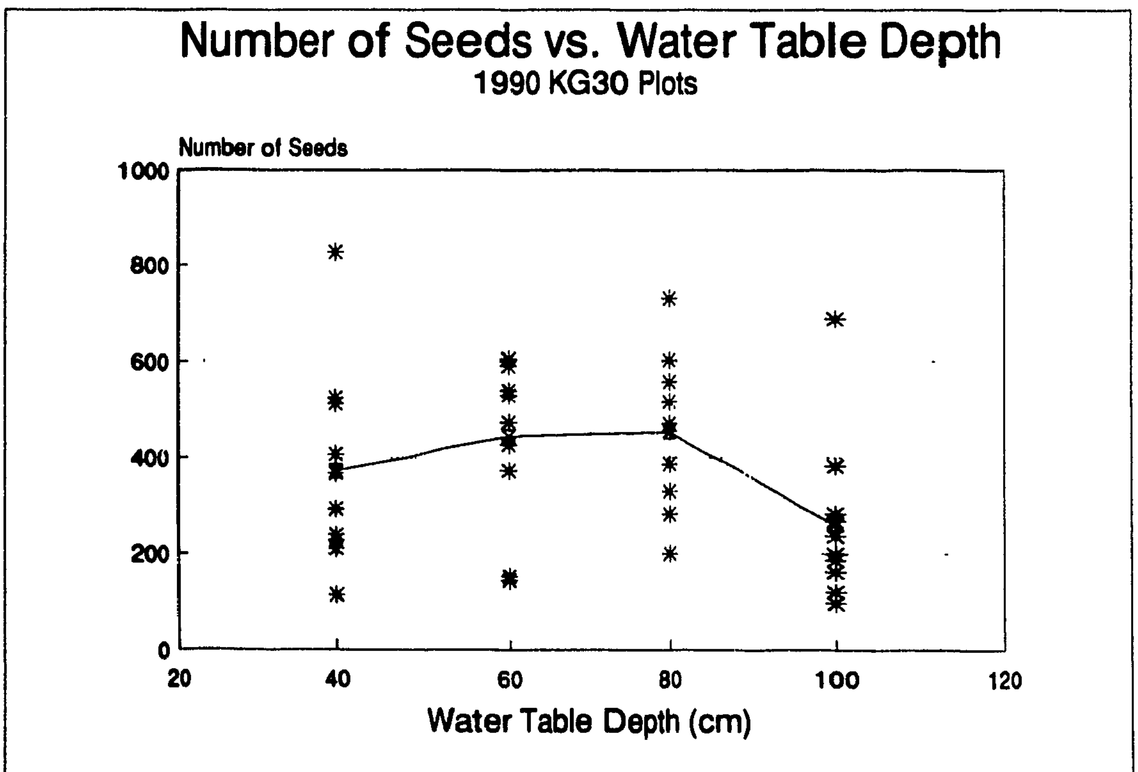

Figure 4.10 Total number of seeds per plant 1990 KG30 plot.

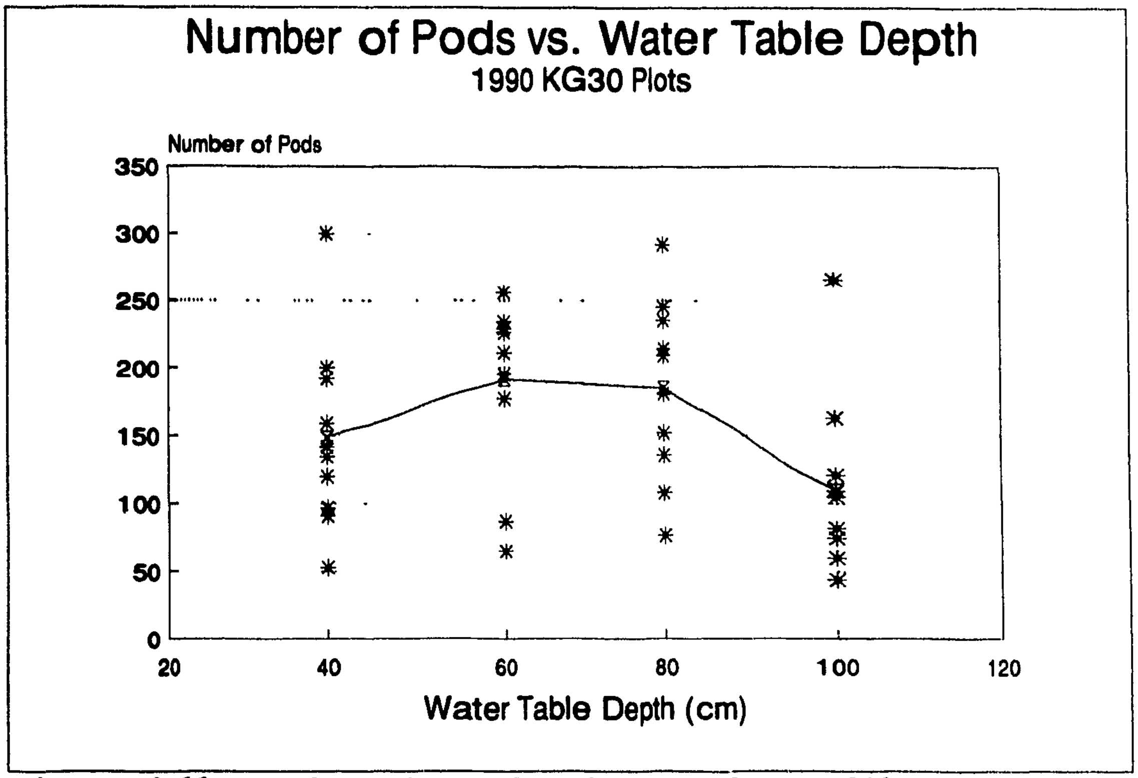

Figure 4.11 Total number of pods per plant 1990 KG30 plot.

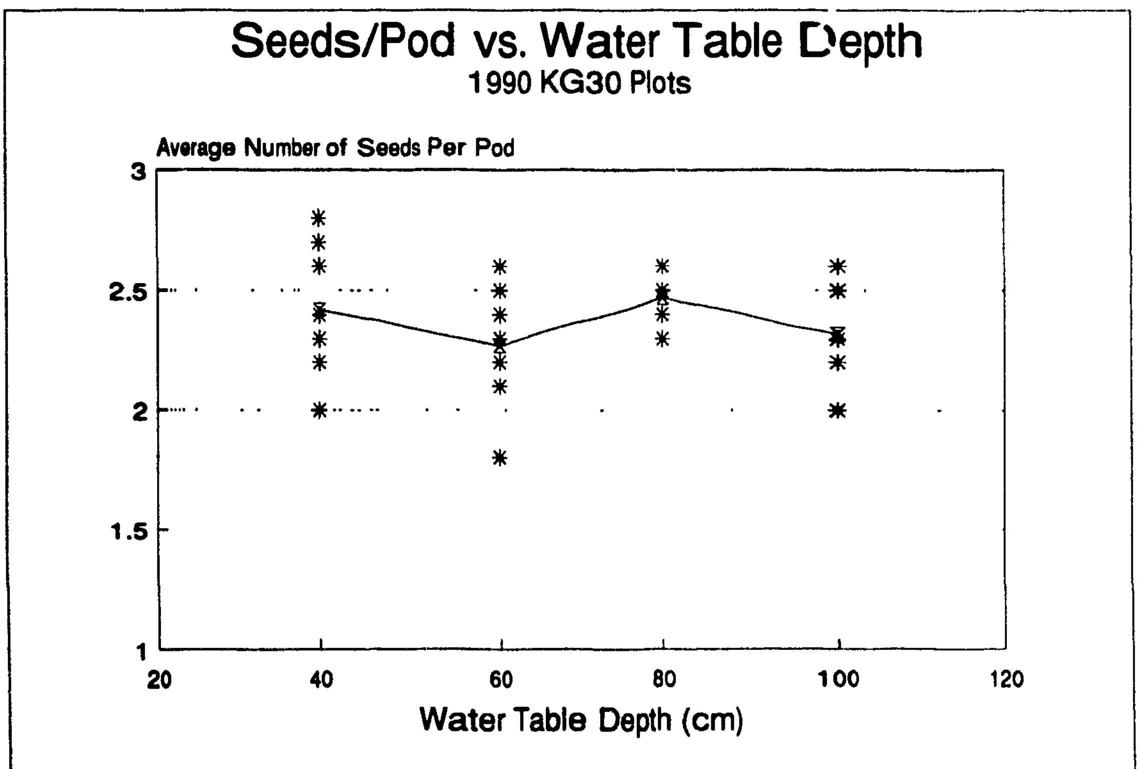

Figure 4.12 Average Number of seeds per pod 1990 KG30 plot.

4.5 Statistical Analysis

The experimental data for 1989 and 1990 growing seasons was tested using SAS. The procedure used was than of general linear model, with water table depth as the treatment and yield and morphology parameters as classes. The same statistical procedures were used for both the 1989 and 1990 experimental years.

Water table treatment was tested for its effects on six parameters. The water table treatments were 40, 60, 80 and 100 cm in depth. The parameters tested were: seed mass per plant, number of seeds per plant, number of pods, number of seeds per pod, moisture content at harvest, and seed protein content at harvest.

No significant differences were found, at the 0.05 level for any of the parameters. This result was expected due to the conditions found in each of the experimental years. In the 1989 year there was very high variability due to population density, damage from herbicides and rodents, and the variable nature of the plants themselves.

In the 1990 season, there were no statistically significant differences due to the water table treatments. In the 1990 growing season, the amount of precipitation that fell was within 3.0 mm of the once in 24 wet season. Results from simulations of the once in 24 wet year show that there is little effect of water table treatment on the yield of soybean. This is shown in Figures 4.25 and 4.26.

Although differences between treatment effects are not significant, trends are visible in the experimental data that can provide useful guidelines for further study. These trends will be discussed in the following sections.

4.6 Results of DRAINMOD simulations

4.6.1 General

The aim of using DRAINMOD was to determine the best water table management practices for growing soybean in a sandy loam soil in Quebec.

The first step was to determine the appropriate drain spacing to use for simulations. Once a drain spacing that provides good drainage as well as good water table control is found, the best water table management practices and weir settings can be found. Simulations were run using 10, 20, 30, and 100 m spacings. The 100 m spacing case was used to simulate a case with poor drainage, while the other cases are lateral drain spacings that may be found on typical farms in Québec.

The 100 m case showed an average relative yield of 47.5% for 24 years of simulations of. In some years there was no crop due to excess soil moisture conditions and delay of planting date and harvest. This shows the need for better drainage, with narrower drain spacings. It was found that with the 30 m drain spacing it was impossible to adequately control the water table in irrigation mode. It was also impossible to provide adequate drainage. It was also found that the relative yields results from the 10 m spacing were not significantly higher than at the 20 m spacing. The installation of lateral drains at the wider spacing would be less expensive, and therefore the better choice.

DRAINMOD produces yield results in terms of the crop stress effects due to soil water deficits and excesses, and planting and harvesting delays. These effects are expressed as a percentage of the maximum attainable crop yield with no crop stresses. The model considers that the crop is undergoing wet stress when the water table rises to within 30 cm of the soil surface. Dry stress occurs when the soil moisture conditions do not satisfy potential evapotranspiration. Yield reductions also occur when there are delays in either planting or harvesting due to soil moisture conditions.

In Table 4.6 relative yield results are shown for three widely different actual climatic conditions. The three conditions are the once-in-24 wet and dry years, and a year that received close to the average depth of rainfall for the 24 year period. These years were: the driest year (1971), an average year (1961), and the wettest year (1972). A summary of total growing season rainfall for these years, as well as the two experimental years, 1989 and 1990, is shown in Table 4.7.

From Table 4.7, it can be seen that the 24 year average compares with the rainfall in 1961, while the 1990 growing season rainfall is within 3 mm of the 1972 rainfall used in the simulation for the wet year. Since the rainfall values are so close between 1972 and 1990, the results between the simulation and the experimental data should also be similar.

4.6.2 Results of simulations for the once in 24 dry year, 1971

The best results were obtained with subirrigation and a weir setting of 40 cm. This was also the best result of all the simulations. A 100 % relative yield was obtained.

Table 4.6 DRAINMOD simulation Relative Yields due to wet or dry stresses. 20 m drain spacing for all cases.

	Relative Yield (%)									
	Dry Year 1971			Ave. Year 1961			Wet Year 1972			Long Term Average Overall
Water Table Control Method	Wet	Dry	Over-all	Wet	Dry	Over-all	Wet	Dry	Over-all	
Sub-irrigation Weir Setting										
40 cm	100	100	100	84.1	100	84.1	62.6	99.7	62.4	89.0
60 cm	100	82.0	82.0	100	98.8	98.8	96.0	98.5	94.6	87.6
80 cm	100	49.7	49.7	100	78.2	78.2	100	96.9	96.9	70.5
Controlled Drainage Weir Setting										
40 cm	100	27.8	27.8	100	73.2	73.2	100	97.5	97.5	56.1
60 cm	100	27.8	27.8	100	73.2	73.2	100	97.5	97.5	55.9
80 cm	100	27.8	27.8	100	67.8	67.8	100	96.8	96.8	54.5
Conventional Drainage 100 cm depth	100	27.0	27.0	100	63.8	63.8	100	96.1	96.1	52.7

Note: The overall stress is the dry stress multiplied by the wet stress as percentages.

Table 4.7 Total growing season rainfall for experimental years and simulation years.

Year	Total Growing Season Rainfall (mm)
1961[1] (once-in-24 average year)	349.6
1971[1] (once-in-24 dry year)	264.2
1972[1] (once-in-24 wet year)	427.0
24 year average[1]	320.5
1989[2]	179.4[3]
1990[2]	423.9

[1] Measured at Dorval International Airport.
[2] Measured at the Macdonald Campus of McGill University.
[3] Complete month data for June were not available.

In the driest year controlled drainage had no effect on raising the water table as seen in Figure 4.13. This would explain the very low relative yields of 27.8 %, which are not significantly higher than the 27.0% found for the drainage case. With controlled drainage in the driest year, 1971 shown in Figure 4.13, the water table is not changed by any of the weir settings. The water tables are almost identical for the entire growing season. In the driest years there is no moisture in the soil profile at the beginning, or rainfall during the growing season to be trapped using controlled drainage. For this reason controlled drainage does not improve the available soil moisture in the profile. Subirrigation shows the best results in the driest years.

In the average and wet years with subirrigation with a weir setting of 40 cm as the management method, the relative yields are reduced due to wet stresses. With the water table maintained as shallow as 40 cm, rainfall can easily raise the water table to a level were it will be harmful to the plants. This is not a problem in the driest year because little precipitation was received during the growing season. Therefore the water table remained at a near constant level, as can be seen in Figure 4.14. The few rises in water table that are noticeable were due to rainfalls that have occurred. The effects of these rainfalls are much greater in wetter years. If only the driest year was considered, the best water table depth would be 40 cm. This, however will not be the best case for wetter years.

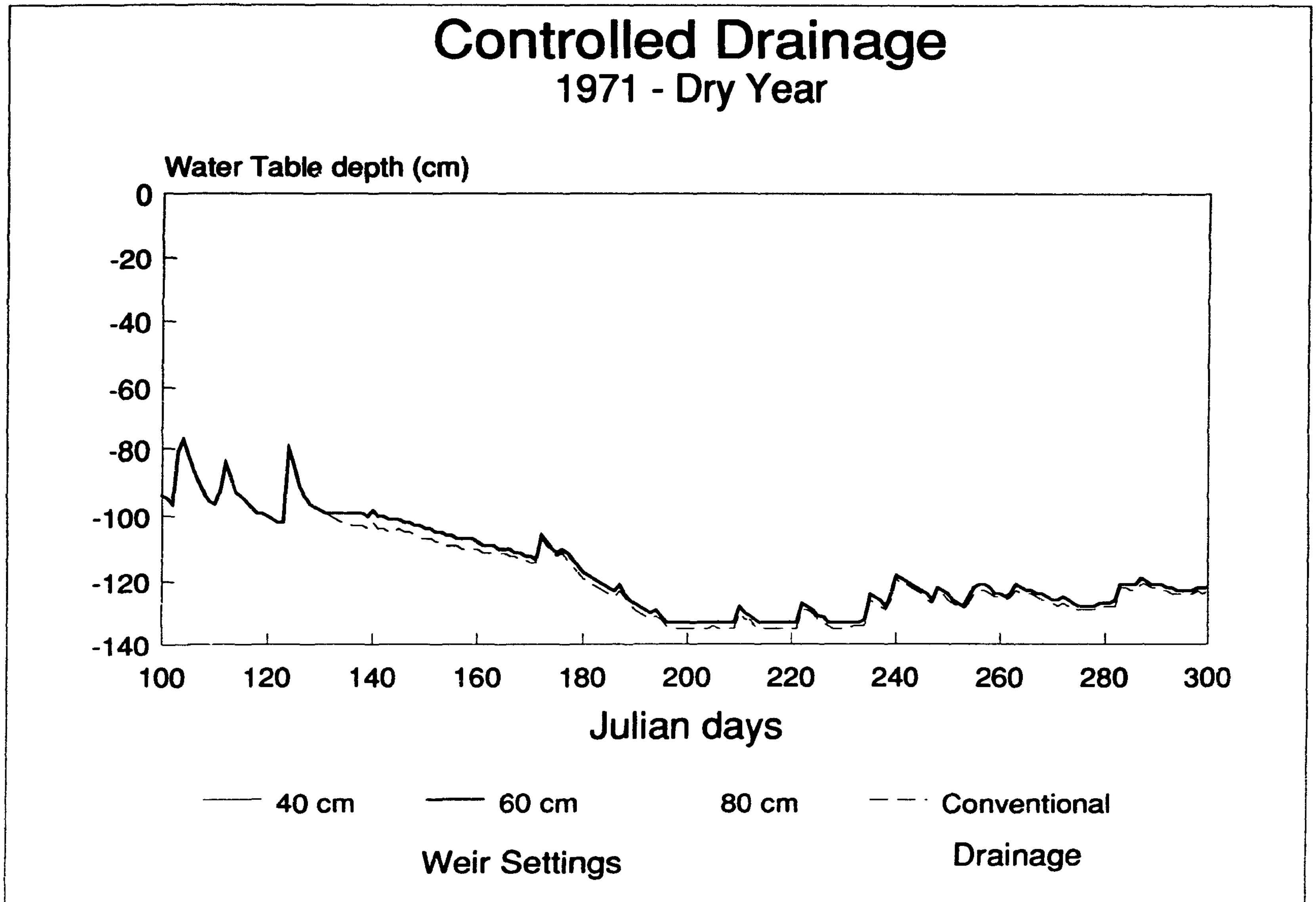

Figure 4.13 Effects of controlled drainage weir settings on water table fluctuations in the once in 24 year dry year (1971).

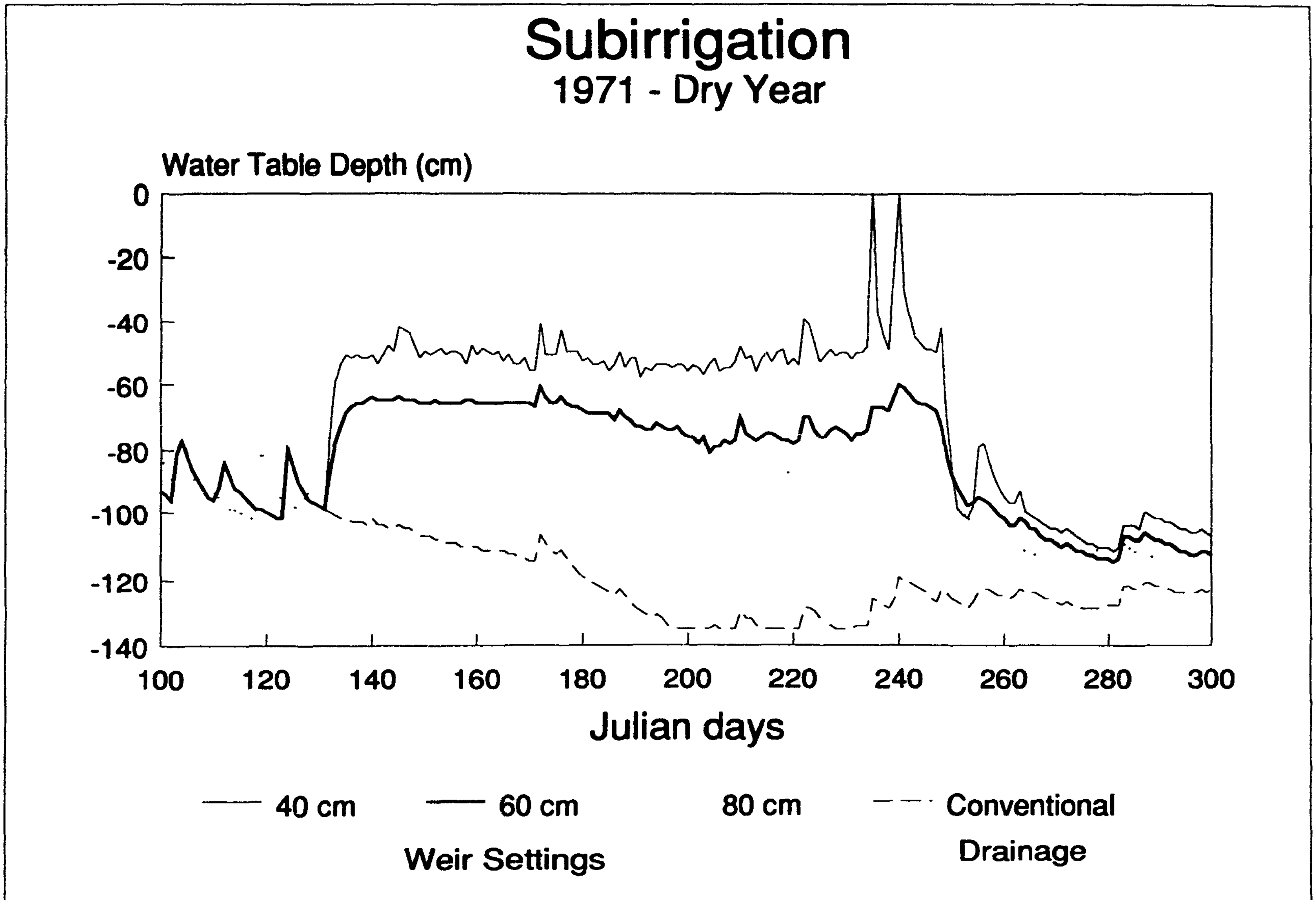

Figure 4.14 Effects of subirrigation weir settings on water table fluctuations in the once in 24 year dry year (1971).

4.6.3 Results of simulations for the average of 24 years, 1961

Relative yield results for the average year show that subirrigation has the highest long term average yields (Table 4.6). Relative yields due controlled drainage were 10% better than those for conventional drainage. Significant improvements were found when subirrigation was used.

A relative yield of 78.2% with subirrigation and 80 cm weir setting was better than any of the controlled drainage cases.

Figure 4.15 shows the water table elevations obtained for controlled drainage. Compared to the driest year yields can be improved by over 40% with controlled drainage. Relative yields were identical under controlled drainage with weir settings of 40 and 60 cm. This is because there was insufficient moisture to raise the water table to a level where the weir setting of 40 cm would have an effect.

Figure 4.16 shows the subirrigation water table shapes for the 1961 growing season. Relative yield was lower at the 40 cm weir setting than in the driest year due to the fact that the water table reached the surface on several occasions. This high water table condition has detrimental effects on the crop and causes reductions in crop yields. The elevated water table occurred at the beginning and at the end of the growing season. The events at the beginning of the growing season, between Mid-May and the first week of June, caused the root zone to be waterlogged. These conditions of high soil moisture at germination and early growth stages could severely retard the growth of the young plants.

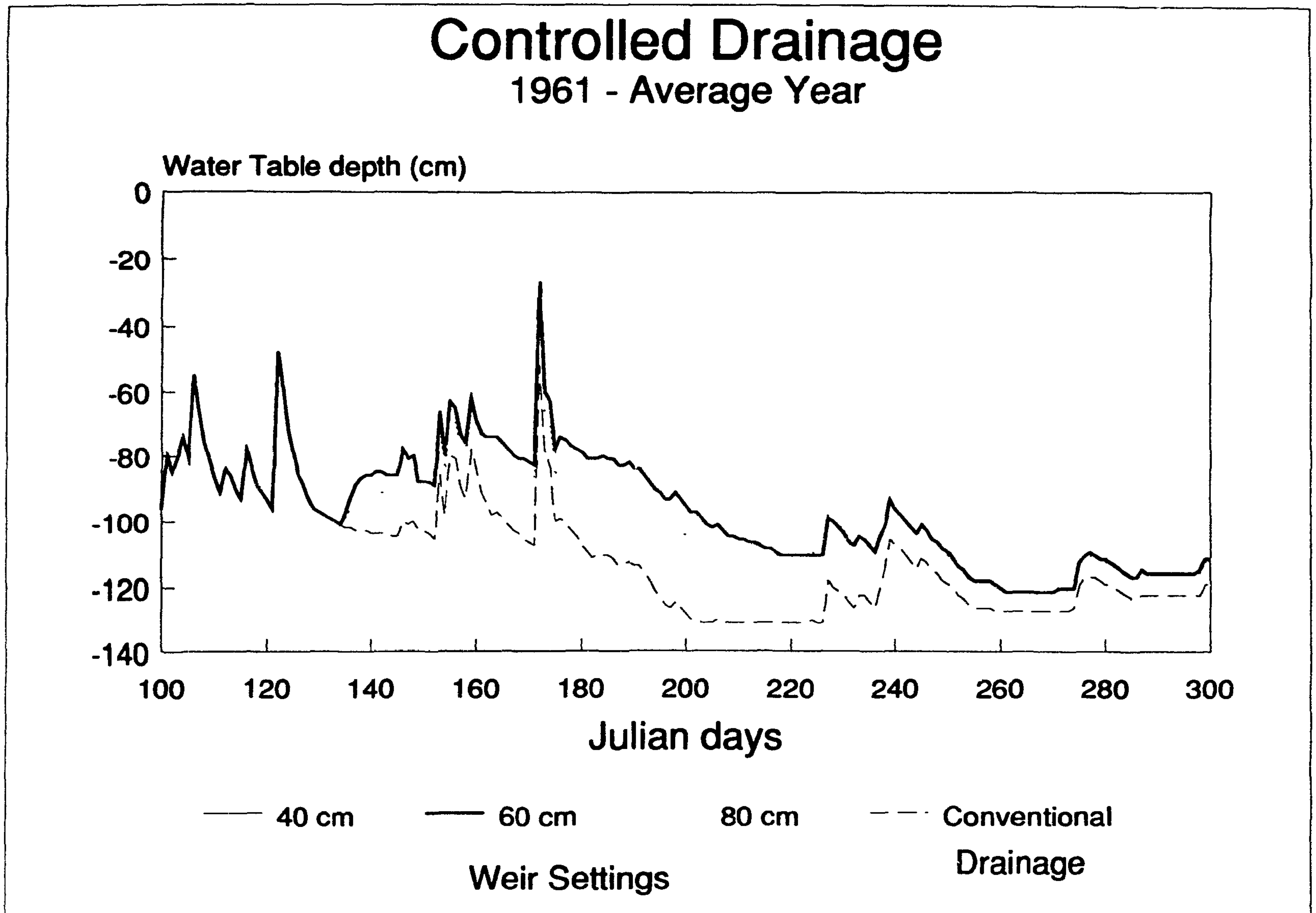

Figure 4.15 Effects of controlled drainage weir settings on water table fluctuations in the average year of 24 years (1961).

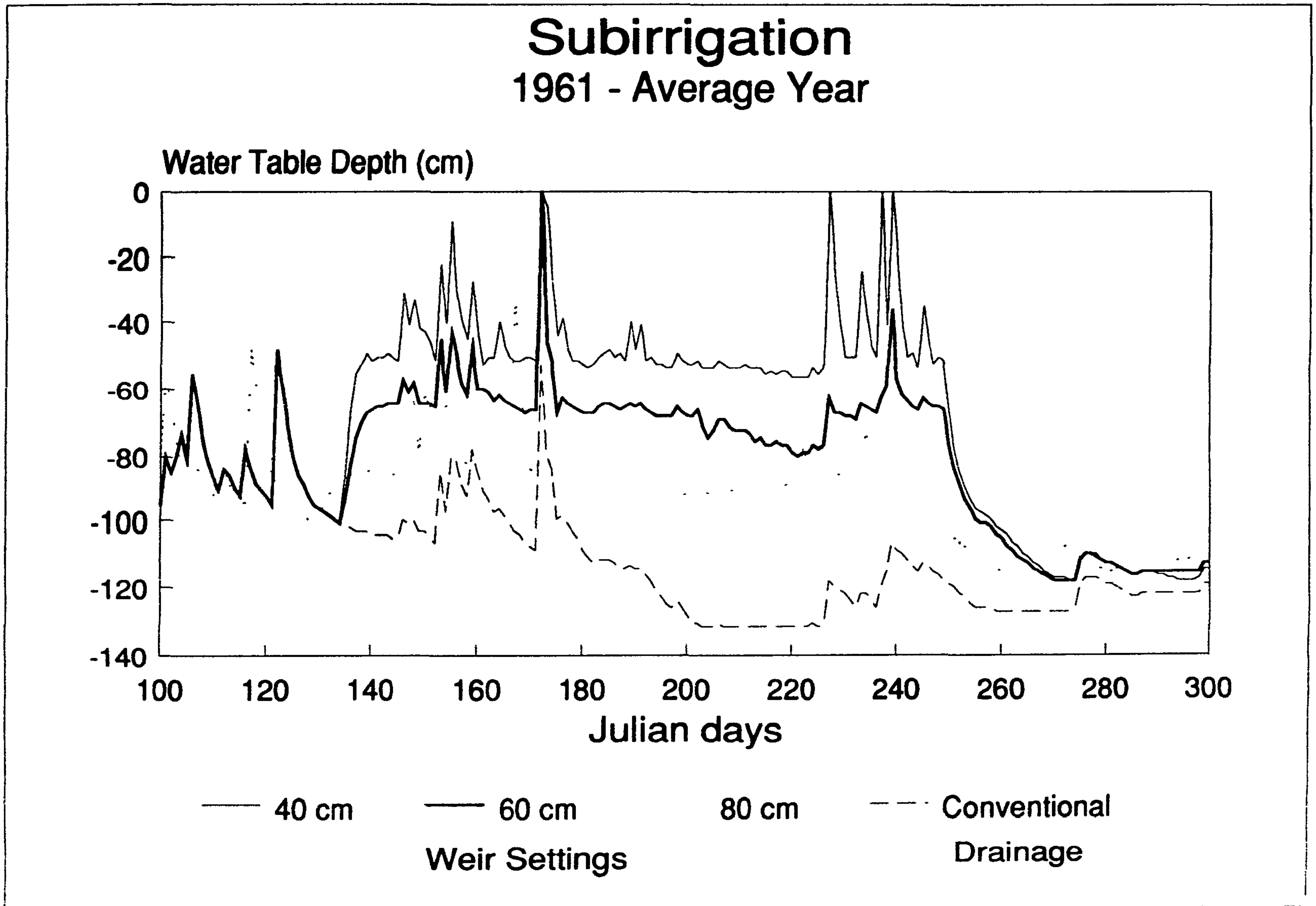

Figure 4.16 Effects of subirrigation weir settings on water table fluctuations in the average year of 24 years (1961).

The 60 cm weir setting achieved a relative crop yield of 98.8%. With the 60 cm weir setting, the water table never reached the surface, and therefore did not cause a yield reduction due to excess soil water. However there was a slight decrease in relative yield due to drought stress. In the average year, relative yields of nearly 80% can be achieved with subirrigation and the deeper weir setting of 80 cm. This would suggest that if there is not sufficient water available to maintain a higher water table, crop yields can still be significantly improved by maintaining the water table closer to 80 cm from the soil surface.

4.6.4 Results of simulations for the once in 24 wet year, 1972

The simulations in the wet year, 1972, showed little variation between the relative yield results found for conventional drainage, controlled drainage, and subirrigation at weir settings of 60 and 80 cm (Table 4.6). This is due to the fact that the rainfall was able to supply the crop evapotranspiration needs.

The amount of rainfall received during the 1990 growing season was very close to that received in 1972. One would expect that the experimental data found in 1990 would show similar trends to that of the simulations performed for 1972. This trend was especially apparent for the Apache crop. The variations were small, with the highest yields found at a water table depth of 80 cm. The lowest average value for number of seeds was found at the 40 cm water table depth, as can be seen in Figure 4.5. This was due to lack of aeration in the root zone as a result of very high water tables following rainfall events. Similar results were found for other parameters and for the KG30 crop, but none was as evident as the number of seeds in the Apache plots.

Figure 4.17 shows that the water table was raised, using controlled drainage, to a level where the plants could benefit. The only combination of water management method and weir setting that gave poor results in the wet year was subirrigation at the shallowest depth. The yield reduction is due mainly to wet stress. The water table was shallower than 30 cm on several occasions during the growing season (Figure 4.18). The rises in water table shown in this figure are due to rainfall events during the growing season.

In the once-in-24 wet year, there is still not sufficient water to raise the water table to the 40 cm depth. This can be seen in Figure 4.17, where the water tables for the 40 and 60 cm weir setting coincide. In the wettest year, conventional drainage gives relative yields of 96.1%. Therefore the benefits of subirrigation, in the wet year are negligible. Controlled drainage with a weir setting of 60 cm improves this relative yield to a maximum of 97.5 %.

Figure 4.18 shows the water table elevations for subirrigation in the once in 24 wet year, 1972. In this year, the water table often reaches the surface when the weir setting is at 60 cm or shallower. The weir setting of 80 cm gave the best relative yield 96.9%, for the subirrigation case. However, it is still slightly lower than what can be obtained with

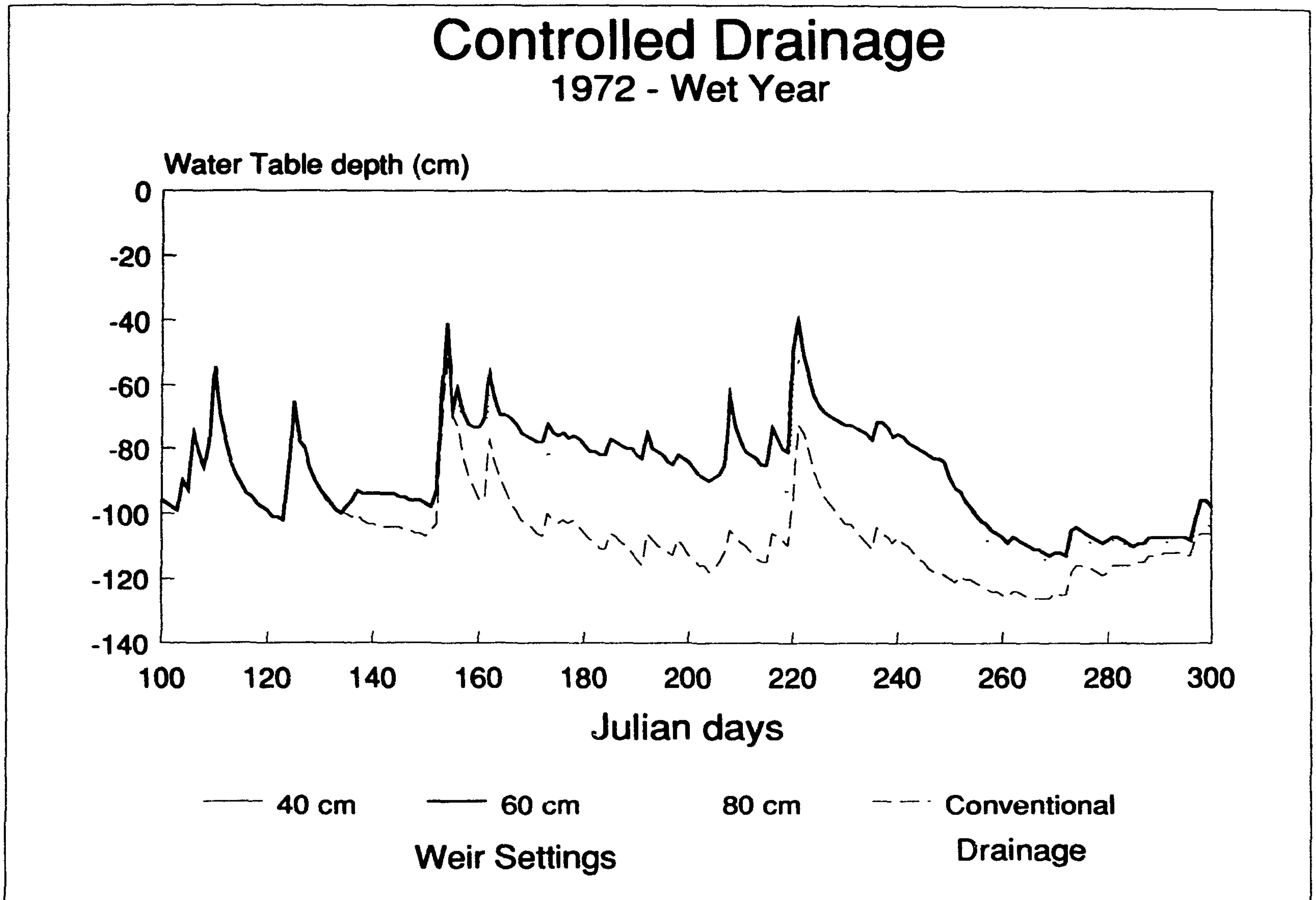

Figure 4.17 Effects of controlled drainage weir settings on water table fluctuations in the once in 24 wet year (1972).

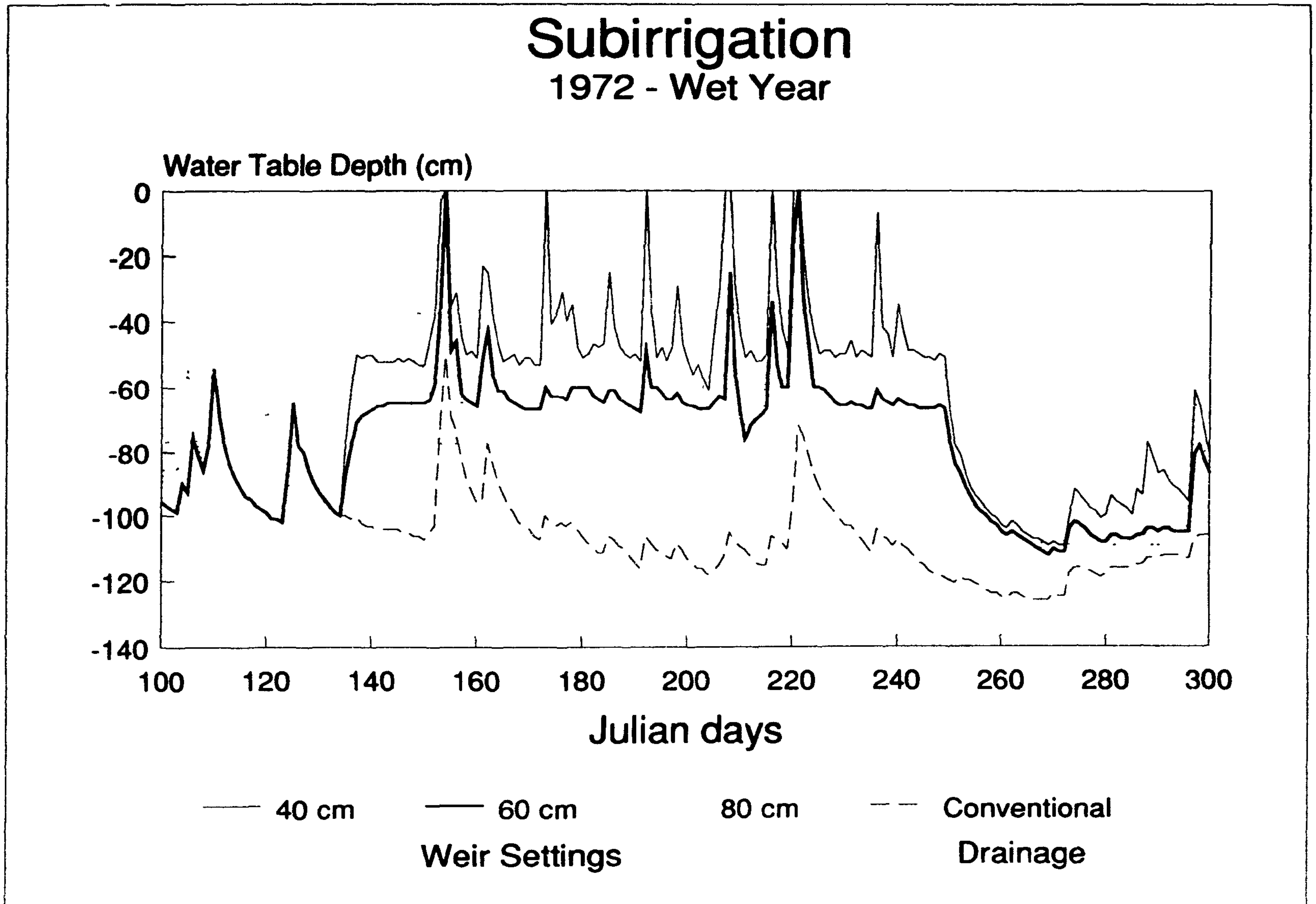

Figure 4.18 Effects of subirrigation weir settings on water table fluctuations in the once in 24 wet year (1972).

controlled drainage. The subirrigation treatment with 60 cm weir setting still gives a high relative yield of 94.6%.

4.6.5 Summary of DRAINMOD results

The simulations showed that the best water management practice is subirrigation. In the dry year, the best yields can be expected at a water table depth of 40 cm; in the average year at 60 cm, and in the wettest year, at 80 cm. The best water table management practice is to control the water table depth at 60 cm, even though the average yield is 1.4% higher at the 40 cm depth. This is because the cost of supplying the additional irrigation water to achieve the 40 cm water table depth would be greater than the potential return. With the water table as shallow as 40 cm there is the risk of damage to the soybean crop from waterlogging of the root zone if large rainfalls were to occur. Another factor that supports the choice of 60 cm as the best depth to maintain the water table is the results found in the wet year under controlled drainage. In the wet year, the controlled drainage system is much like a subirrigation system. The difference is that the irrigation water is being supplied by rainfall. In the wet year, controlled drainage was able to maintain the water table near 60 cm depth and give the second highest yield results.

When considering the three cases of once-in-24 dry, average and wet years, the combination of water table management method and weir setting that consistently gives the best relative yields results is that of subirrigation with a weir setting of 60 cm. This is also justified from the field experiment results, where a water table depth between 60 and 80 cm gave the best crop yields.

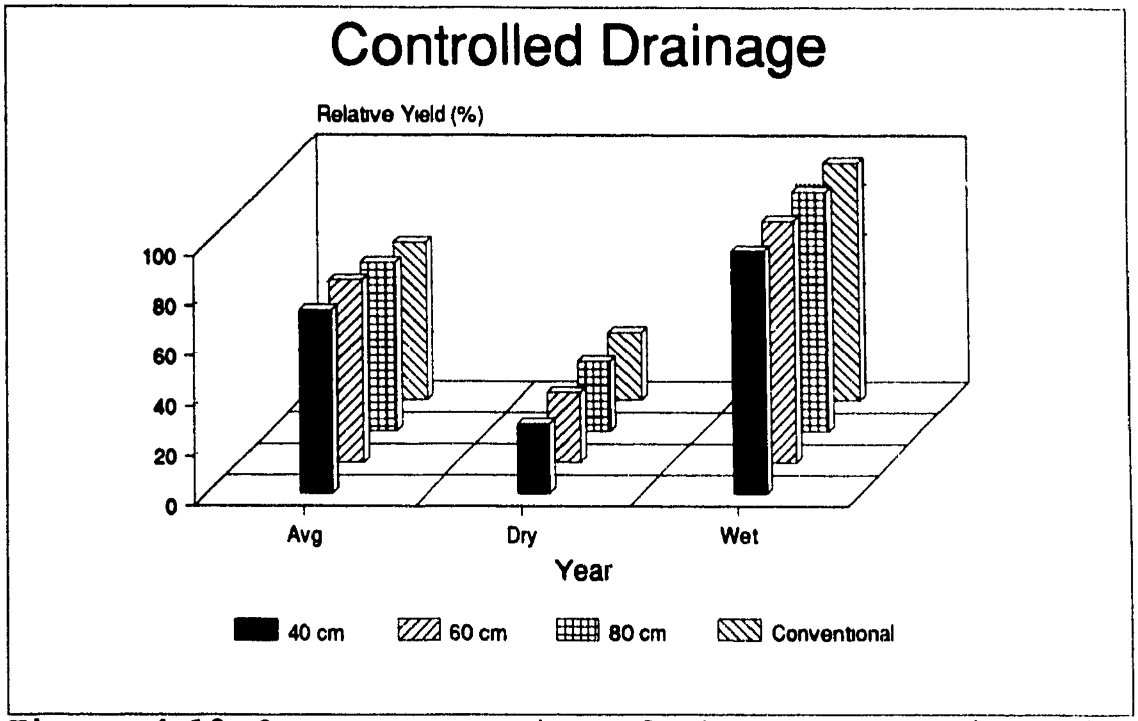

Figure 4.19 3D representation of the DRAINMOD simulation results for controlled Drainage.

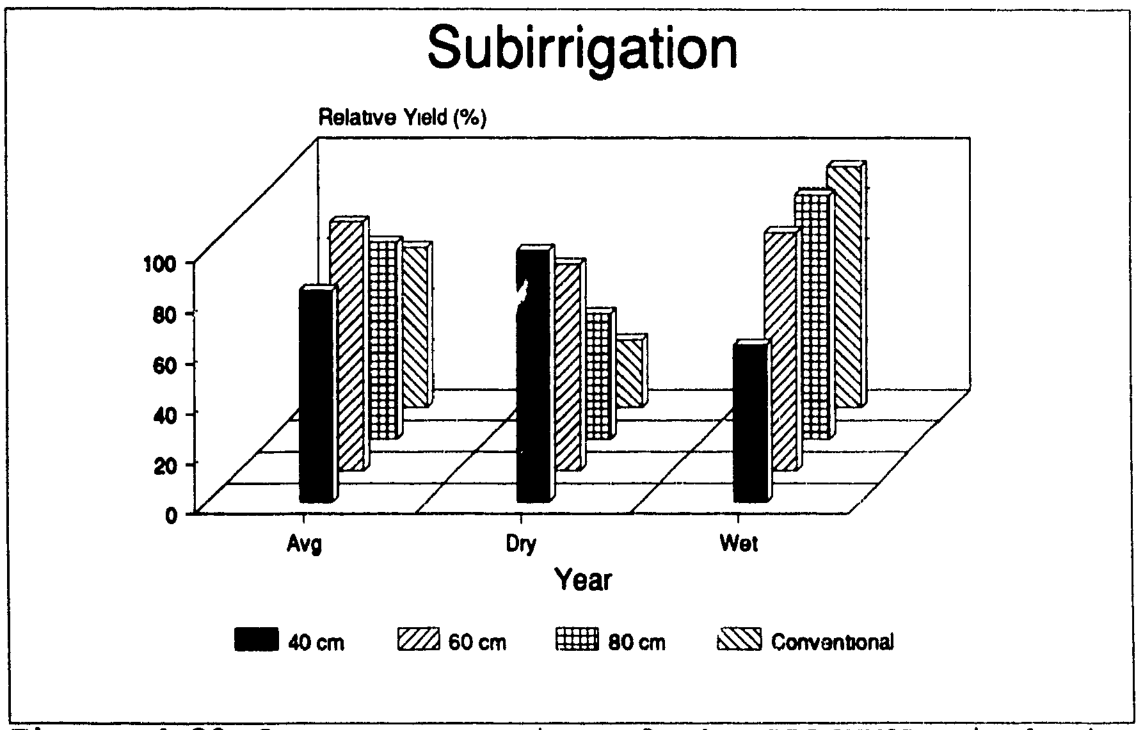

Figure 4.20 3D representation of the DRAINMOD simulation results using Subirrigation.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary

A water table management experiment was carried out at the Horticulture Research Station, Macdonald Campus of M^{c}Gill University. The experiment was conducted in 1989 and 1990 using lysimeters to test the effects of water table levels on soybean growth. The lysimeters were repacked with a sandy loam soil.

The experiment was divided into 4 plots of 20 lysimeters each. In each plot there were 5 replicates of 4 water table treatments. The water table depths tested were 40, 60, 80, and 100 cm. The 100 cm water table was considered similar to conventional drainage. Each lysimeter was equipped with an observation pipe for measuring the water table position.

The water table treatments were maintained for the duration of the growing seasons. Water table levels were maintained using 4 control chambers per test plot. The water level in the control chambers was checked and adjusted on a daily basis.

DRAINMOD, a water table management computer model was used with 24 years of climatic data to determine the benefits of different water table management systems.

Crop yield was measured in terms of number of seeds per plant, total mass of seeds per plant, number of seeds per pod and crude protein content.

The crop yield data and DRAINMOD simulations were used to establish water table management strategies for soybean production on a sandy loam soil in Québec.

5.2 Conclusions

1. Water table conditions affect soybean yield. Too shallow a water table will result in waterlogging of the root zone and will significantly reduce yield, even killing plants. To deep a water table and soybean will suffer from drought stress and have significantly reduced yields.

2. Conventional drainage is a must in the Quebec climate for the growth of soybean. Without drainage, long term average relative yields will always be below 50%.

3. Results of simulations show that controlled drainage improves the relative yields for soybean. Controlled drainage is a sufficient water table control method in the wetter than average years. In the wettest year, controlled drainage is capable of producing relative yields of greater than 90%.

4. Simulations show that subirrigation with water table depth of 60 cm is the best combination of management practices for long term average maximum potential yield.

5. Soybean is a crop that is very adaptive to differing soil moisture conditions. Although a 60 cm water table gives the best yield, water tables of up to 80 cm in depth give very good results. Soybean will not suffer if there are short term dry periods, which can occur from an

intermittent water supply, for this reason soybean is well adapted to water table management.

6. Water table depth was found to have an effect on all plant yield parameters. A water table that is too shallow reduces plant yields due to waterlogging of the root zone. A water table that is too deep reduces plant yields due to dry stress. A water table between 50 to 80 cm in depth gives good crop yields. Water table depth showed no significant difference on protein concentration. Therefore increasing the seed mass per plant results in more edible protein produced, no matter under what water table depth the plants were grown.

7. The water management model DRAINMOD Version 4.0, is a useful tool when deriving water table management system design parameters. It enable the user to consider many years of data, and many different conditions, that would otherwise be too costly to attempt. The computer model has helped to establish the important design criteria for a water table management system such as drain spacing and weir depth. Drain spacing should be small enough to provide good drainage, while being able to control the water table height in subirrigation mode. In the case of the soil used in this experiment, a drain spacing of 20 m was selected. The drain spacing of 10 m actually gave higher average relative yield by around 2%, but this

spacing would cost twice as much as the more than adequate 20 m spacing. As was stated above, the optimum water table depth is 60 cm, although a water table range between 50 and 80 cm would probably produces good yield results.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

The lysimeters used for this project might be used in the future to:

1. Test the soybean crop using the established lysimeter experiment for further growing seasons to try and establish similarities between the simulation results and the experimental findings.
2. Find whether water table management which reduces summer drainage also reduces the amounts of nitrates or other fertilizer components in the drainage water, compared to free outlet subsurface drainage.
3. The lysimeters from this experiment, could be used with other crops to determine desirable water table depths, and water management scenarios. Important crops for consideration are sweet corn, grain corn, strawberries, green and yellow string beans,tomatoes, and peppers.
4. Lysimeters could be used to test or calibrate models for the movement of pesticides, such as PESTFADE (Clemente, 1992).
5. Drainage lysimeters might be used to determine actual evapotranspiration of some crops throughout the growing season, under different water management scenarios.

REFERENCES

Ashley, D. A. 1983. Soybean. In Teare and M. M. Peet (eds.). Crop-water relations. Wiley Interscience, New York, pp. 389-422.

Baumer, O. and J. Rice. 1988. Methods to Predict Soil Input Data For DRAINMOD. ASAE paper number 88-2564.

Brady, R. A., L. R. Stone, C. D. Nickell, and W. L. Powers, 1974. Water conservation through proper timing of soybean irrigation. J. of Soil and Water Conserv. 29(6): 266-268.

Broughton, R.S. 1972. The performance of subsurface drainage systems on two St. Lawrence lowland soils. Ph. D. Thesis, Agricultural Engineering Dept. McGill University, Montreal, Quebec.

Camp, C.R., G.D. Christenbury, and C. W. Doty, 1988. Scheduling irrigation for corn and soybean in the Southeastern Coastal Plain. Trans. ASAE 31(2): 513-518.

Clemente, C.S. 1991. Pestfade, A pseticide fate and transport model. Ph.D. Thesis, Agricultural Engineering Dept. McGill University, Montreal, Quebec.

Doss, B. D., R.W. Pearson, and H. T. Rodgers, 1974. Effect of soil water stress at various growth stages on soybean yield. Agron. J. 66: 297-299.

Doss, B.D., D.L. Thurlow. 1974. Irrigation , Row width, and Plant Population in Relation to Growth Characteristics of Two soybean cultivars. Agron. J. 66:297-299.

Doty, C. W., S. T. Currin, and R. E. McLin, 1975. Controlled subsurface drainage for Southern Coastal Plains soil. J.Soil and Water Conserv. 30: 84-85.

Drablos, C.J.W., K.D. Konya, P.W. Simmons, M.C. Hirschi. 1988. Estimating Soil Parameters Used in DRAINMOD For Artificially Drained Soils in Illinois. ASAE paper number 88-2617.

Drouet, M.P., 1989. An Economic Analysis for Subsurface Irrigation of Maize in Québec. MSC. Thesis, McGill University, Montréal, Québec, Canada.

Dufresne, M.E., 1988. Compte-Rendu. Culture du Soya: Observations et Commentaires, Bureau de Renseignments Agricole Sorel, Québec.

Fehr, W. R., C. E. Cavines, D. T. Burmood, and J. S. Pennington, 1971. Stage of development descriptions for soybeans, *Glycine Max* (L) Merrill. Crop Science 2: 929-931.

Food and Agriculture Organization, 1977. Crop Water Requirements, FAO irrigation and Drainage paper 24, Rome 1977.

Fox, R. L., J. T. Phelan, and W. Criddle, 1956. Design of subsurface systems. Agric. Eng. 37(2): 103-107.

Galganov, Y.T., 1991. Subsurface Irrigation of Soybean. Ph.D. Thesis. McGill University, Montréal, Québec, Canada.

Gouvernment du Québec, Bureau de la Statistique du Québec, Révision des principales Grande Cultures, 1981-1986.

Gouvernment du Québec, Bureau de la Statistique du Québec, Grande Cultures: Superficie, Production et Valeur, 1990.

Hearn, A. B., and G. A. Constable, 1981. Irrigation for crops in a sub-humid environment. V. Stressing analysis for Soybeans and an economic evaluation of strategies. Irrig. Sci. 3: 1-15.

Heatherly, L. G. 1988. Planting date, row spacing, and irrigation effects on soybean grown on clay soil. Agron. J. 80: 227-231.

Jones, J. W., B. Zur, and K. J. Boote, 1983. Field evaluations of a water relations model for soybean. II. Diurnal fluctuations. Agron. J. 75: 281-286.

Kadhem, F. A., J. E. Specht, and J. H. Williams, 1985. Soybean irrigation serially timed during stages R1 to R6. II. Yield component responses. Agron. J. 77: 299-304.

Konyha, K.D., J.E. Parsons and R.W.Skaggs, 1989. DRAINMOD User's Manual, Interim Technical Release Draft 10/1989. Biological and Agricultural Engineering Department, North Carolina State University, Raleigh NC.

Luthin, J. N., 1978. Drainage Engineering. Robert E. Krigger Publ. Co. New York, p. 281.

Madramootoo, C.A., 1990. Assessing Drainage Benefits on Heavy Clay Soils in Quebec. ASAE transactions of Soil and Water Div. June 1990.

Mahler, R. L., and A. G. Wollum, 1981. The influence of irrigation and *Rhizobium japonicum* strains on yields of soybeans grown in Lakeland sand. Agron. J. 73: 647-650.

Matson, Arnold L., 1964. Some Factors Affecting the Yield Response of Soybeans to Irrigation. Agron. J. 56: pages 552-555

Meyer, G. E. 1985. Simulation of moisture stress effects on soybean yield components in Nebraska. Trans. ASAE 28(1): 118-128.

Minchen, F. R., and J. S. Pate, 1975. Effects of water, aeration, and salt regime on nitrogen fixation in a nodulate legume: Definition of an optimum environment. J. Ext. Bot 26: 60-69.

Papineau, F., 1987. Land and Water Appraisal for Irrigation in Richelieu and St-Hyacinthe Counties, Québec. Msc. Thesis. McGill University, Montreal, Québec, Canada.

Sallam, A. and H.D. Scott. 1987. Effects of Prolonged Flooding on Soybeans During Early Vegetative Growth. Soil Science, July 1987, vol 144, No. 1, pages 61-66.

Schwab, G. O., E. D. Desmond, and G. F. Barkle, 1985. Soybean yield response to excess water. ASAE Paper No: 85-2562.

Scott, H.D., J.A. Ferguson, and L.S. Wood. 1987. Water Use, Yield, and Dry Matter Accumulation by Determinate soybean Grown in a Humid Region. Agron. J. Sep-Oct 1987 Vol 79 No. 5, pages 870-875.

Scott, W.O., and S. R. Aldrich. 1983. Modern Soybean Production. S & A Publications, Champaign Illinois.

Sipp, S.K., W.D. Lembke, C.W. Boast, J.H. Peverly, M.D. Thorne, P.N. Walker. 1986. Water Management of Corn and Soybeans on a Claypan Soil. Transactions of the ASAE, 1986, pages 780-784

Skaggs, R.W., F.J. Kriz and R.Bernal, 1972. Irrigation Through Subsurface Drains. Journal of the Irrigation and Drainage Division, ASCE, vol. 98, pp 363-373.

Skaggs, R. W. 1979. Water movement factors important to design and operation of subirrigation systems. ASAE Paper No: 79-2543.

Skaggs, R.W., Konya, K.D., 1988. DRAINMOD Version 4.0 - An Overview. ASAE paper number 88-2563.

Sojka, R.E., H.D. Scott, J.A.Ferguson, and R. M. Rutledge. 1977. Relation of Plant Water Status to Soybean Growth. pages 182-187.

Stegman, E. C. 1989. Soybean yields as influenced by timing of ET deficits. Trans ASAE 32(2): 551-556.

Van Doren, D. M.,Jr., and D. C. Reicosky, 1987. Tillage and irrigation. In Wilcox, J. R. (ed.). Soybeans: Improvements, production and uses. 2nd ed. Monograph No. 16. Am. Soc. of Agron.

Van Schilfgaarde, J., and R. E. Williamson, 1961. Growth chamber for evaluating excess soil moisture conditions for drainage design. Trans. ASAE 4: 108-111.

Van Schilfgaarde, J., and R. E. Williamson, 1965. Studies of crop response to drainage: I. Growth chambers. Trans. ASAE 8: 94-97.

von Hoyningen Huene, B., N.A.Memon and R.S. Broughton, 1985. Water Table Response to Subsurface Irrigation. ASAE paper no 85-2619.ASAE St. Joseph, MI 49085

Willatt, S.T. and H.M. Taylor 1977. Water uptake by soya-bean roots as affected by their depth and by soil water content. J. agric. Sci., Camb. (1978). 90, 205-213.

Williamson, R. E., and G. J. Kriz, 1970. Response of agricultural crops to flooding, depth of water table and soil gaseous ccomposition. Trans. ASAE 13(1): 216-219.

APPENDICES

Appendix A

1989 Apache Variety
Yield Results

Table A1 1989 Apache yield data for the 40 cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Bean Mass 14% MC	Moisture Content (harvest)	Protein Content
	#	#	#	g	%	%
A1 E	321	153	2.1	54.93	31.64	36.87
A1 W	152	72	2.1	24.14	39.23	36.10
A4 E	43	29	1.5	6.09	16.50	45.88
A4 W	131	63	2.1	12.04	73.83	43.04
B5 E	339	166	2.0	59.80	16.22	35.62
B5 W	121	72	1.7	21.98	18.34	37.37
C3 E	343	171	2.0	68.28	21.69	36.33
C3 W	153	86	1.8	25.37	17.69	38.06
D2 E	253	111	2.3	49.25	23.01	37.33
D2 W	362	158	2.3	67.14	27.14	37.04
Totals	2218	1081		389.03	285.29	383.64
Averages	221.8	108.1	2.0	38.90	28.53	38.36

Table A2 1989 Apache yield data for the 60 cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Bean Mass 14% MC	Moisture Content (harvest)	Protein Content
	#	#	#	g	%	%
A2 E	152	66	2.3	32.88	25.40	40.19
A2 W	378	182	2.1	63.96	19.09	38.31
B3 C	103	57	1.8	16.94	18.46	39.88
B3 E	152	74	2.1	29.70	21.07	38.53
B3 W	130	62	2.1	25.10	20.04	36.18
C5 E	281	122	2.3	61.33	18.32	38.00
C5 W	260	149	1.7	45.23	28.62	37.47
D1 E	84	38	2.2	12.63	38.20	37.70
D1 W	70	34	2.1	9.91	35.53	38.34
D4 E	291	157	1.9	47.37	19.19	34.89
D4 W	334	227	1.5	62.94	19.04	32.47
Totals	2235	1168		407.97		
Averages	203.2	106.2	2.0	37.09	23.90	37.45

Table A3 1989 Apache yield data for the 80 cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Bean Mass 14% MC	Moisture Content (harvest)	Protein Content
	#	#	#	g	%	%
A5 E	189	119	1.6	34.51	21.73	40.15
A5 W	428	188	2.3	38.55	19.92	43.97
B2 E	176	81	2.2	29.72	31.47	36.80
B2 W	90	49	1.8	14.21	15.92	38.39
C1 E	73	37	2.0	10.66	17.80	39.42
C1 W	169	95	1.8	23.50	23.42	39.20
C4 E	434	245	1.8	68.49	19.25	38.42
C4 W	333	172	1.9	57.79	17.51	35.84
D3 E	187	102	1.8	28.63	19.39	37.60
D3 W	318	191	1.7	48.44	19.72	36.97
Totals	2397	1279		354.50		
Averages	239.7	127.9	1.9	35.45	20.61	38.68

Table A4 1989 Apache yield data for the 100cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Bean Mass 14% MC	Moisture Content (harvest)	Protein Content
	#	#	#	g	%	%
A3 E	118	54	2.2	18.96	25.85	37.04
A3 W	112	48	2.3	18.81	29.92	38.00
B1 E	208	88	2.4	28.05	20.47	38.86
B1 W	89	51	1.7	12.22	21.76	39.35
B4 E	463	198	2.3	70.56	17.34	39.18
B4 W	246	143	1.7	37.87	18.23	37.84
C2 E	66	38	1.7	9.00	20.45	42.02
C2 W	152	75	2.0	24.83	20.31	38.39
D5 E	311	171	1.8	52.61	18.63	36.96
D5 W	391	161	2.4	73.05	18.03	35.26
Totals	2156	1027		345.95		
Averages	215.6	102.7	2.1	34.59	21.10	38.29

Appendix B

1990 Apache Variety Yield Results

Table B1 1990 Apache Yield data for the 40 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
A1	574	233	2.5	289	107.91	35.74
A4	436	195	2.2	248	67.50	43.50
B5	386	197	2.0	150	58.10	31.14
C3	245	139	1.8	130	35.08	36.83
D2	449	194	2.3	247	75.92	36.56
E1	460	189	2.4	283	91.82	40.31
E4	356	157	2.3	122	52.46	31.00
F5	394	165	2.4	144	71.03	37.51
G3	169	86	2.0	94	27.81	38.19
H2	269	117	2.3	119	46.68	49.46
Totals	3738	1672		1826	634.31	
Averages	373.8	167.2	2.2	182.6	63.43	38.02
CV %	31.83	26.15	10.58	41.11	39.03	14.46

Table B2 1990 Apache Yield data for the 60 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
A2	276	160	1.7	123	41.01	32.26
B3	478	205	2.3	237	86.79	30.13
C5	507	213	2.4	244	99.80	33.49
D1	172	96	1.8	92	28.34	86.98
D4	384	197	1.9	181	57.93	34.52
E2	241	140	1.7	105	39.96	59.51
F3	487	198	2.5	223	90.80	39.31
G5	393	239	1.6	356	99.95	31.50
H1	336	140	2.4	181	79.86	33.70
H4	584	228	2.6	352	86.97	36.90
Totals	3858	1816		2094	711.41	
Averages	385.8	181.6	2.1	209.4	71.14	41.83
CV %	33.90	25.13	17.23	44.38	37.76	42.96

Table B3 1990 Apache Yield data for the 80 cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Total Branch Length	Total Bean Dry Mass	Moisture Content
	#	#	#	cm	g	%
A5	499	215	2.3	213	93.25	35.40
B2	451	183	2.5	183	84.00	35.57
C1	500	234	2.1	191	99.31	35.40
C4	569	230	2.5	221	105.42	33.41
D3	487	208	2.3	206	88.87	38.42
E5	372	184	2.0	146	62.47	33.42
F1	458	187	2.4	151	81.06	28.61
F4	120	55	2.2	112	17.41	33.66
G2	491	198	2.5	222	89.38	29.23
H3	389	186	2.1	132	55.04	47.57
Totals	4336	1880		1777	776.21	
Averages	433.6	188	2.3	177.7	77.62	35.07
CV %	28.58	26.80	7.62	22.36	33.73	15.06

Table B4 1990 Apache Yield data for the 100cm water table treatment

Location	Number of Beans	Number of Pods	Beans per Pod	Total Branch Length	Total Bean Dry Mass	Moisture Content
	#	#	#	cm	g	%
A3	503	217	2.3	202	88.73	34.82
B1	431	173	2.5	192	69.34	37.90
B4	368	174	2.1	195	62.22	42.03
C2	401	187	2.1	240	66.95	28.36
D5	424	190	2.2	217	98.03	16.72
E3	422	202	2.1	111	68.43	31.95
F2	593	248	2.4	247	110.77	36.20
G1	311	140	2.2	114	61.31	34.28
G4	440	185	2.4	169	78.30	26.88
H5	319	146	2.2	134	55.33	31.66
Totals	4212	1862		1821	759.41	
Averages	421.2	186.2	2.3	182.1	75.94	32.08
CV %	19.57	16.93	6.14	28.08	24.03	22.73

Appendix C

1990 KG30 Variety Yield Results

Table C1 1990 KG30 Yield data for the 40 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
I3	114	53	2.2	70	16.88	50.65
J1	367	142	2.6	276	56.25	54.70
J4	293	135	2.2	105	25.42	94.22
K2	239	120	2.0	107	28.21	66.18
L5	513	200	2.6	222	68.97	44.29
M1	210	91	2.3	341	90.53	41.52
M4	228	97	2.4	116	22.24	79.36
N5	525	192	2.7	372	55.26	51.59
O3	406	159	2.6	217	56.96	56.62
P2	827	300	2.8	525	117.88	47.77
Totals	3722	1489		2351	538.60	
Averages	372.2	148.9	2.4	235.1	53.86	58.69
CV %	55.85	46.81	10.80	61.96	60.39	28.41

Table C2 1990 KG30 Yield data for the 60 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
I2	144	65	2.2	50	19.52	51.84
J3	373	177	2.1	165	31.24	97.86
K5	530	211	2.5	241	69.50	61.24
L1	153	87	1.8	122	43.15	51.15
L4	427	195	2.2	169	54.55	54.26
M2	540	229	2.4	285	83.01	51.33
N3	591	256	2.3	316	82.89	51.96
O5	474	226	2.1	170	59.31	62.87
P1	604	234	2.6	308	84.78	43.45
P4	606	234	2.6	328	83.38	45.51
Totals	4442	1914		2154	611.33	
Averages	444.2	191.4	2.3	215.4	61.13	57.15
CV %	39.06	33.90	11.31	43.69	38.83	27.13

Table C3 1990 KG30 Yield data for the 80 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
I5	330	136	2.4	123	37.92	71.23
J2	455	181	2.5	214	56.50	68.83
K1	200	77	2.6	72	27.87	58.34
K4	387	152	2.5	120	44.27	45.38
L3	517	214	2.4	211	59.48	59.08
M5	283	108	2.6	123	29.07	78.29
N2	730	292	2.5	390	109.05	61.21
O1	603	235	2.6	261	89.23	49.34
O4	471	209	2.3	154	69.36	14.27
P3	558	245	2.3	234	48.71	42.99
Totals	4534	1849		1902	571.46	
Averages	453.4	184.9	2.5	190.2	57.15	54.90
CV %	35.03	36.08	5.14	48.66	45.67	33.21

Table C4 1990 KG30 Yield data for the 100 cm water table treatment

Location	Number of Beans #	Number of Pods #	Beans per Pod #	Total Branch Length cm	Total Bean Dry Mass g	Moisture Content %
I1	236	105	2.2	115	34.64	51.18
I4	97	44	2.2	73	14.93	58.07
J5	186	82	2.3	80	25.90	49.85
K3	162	75	2.2	75	18.58	69.86
L2	382	163	2.3	73	54.72	42.40
M3	283	121	2.3	152	34.78	53.51
N1	120	60	2.0	126	42.65	55.78
N4	687	266	2.6	340	105.20	46.40
O2	268	109	2.5	124	33.05	77.94
P5	198	75	2.6	65	26.27	55.23
Totals	2619	1100		1223	390.72	
Averages	261.9	110.0	2.3	122.3	39.07	56.02
CV %	65.33	58.59	8.37	67.05	66.33	19.03

Appendix D

Drainmod Sample Output
and
Listing of all Input Parameters

```
*****************************************************************************

                              D R A I N M O D

                    VERSION: NORTH CAROLINA MICRO 3.60
                LAST UPDATE: NOV 1987
                   LANGUAGE: MS FORTRAN v 4.01

          DRAINMOD IS A FIELD-SCALE HYDROLOGIC MODEL DEVELOPED FOR
          THE DESIGN OF SUBSURFACE DRAINAGE SYSTEMS. THE MODEL WAS
          DEVELOPED BY RESEARCHERS AT THE DEPT. OF BIOLOGICAL AND
          AGRICULTURAL ENGINEERING, NORTH CAROLINA STATE UNIVERSITY
          UNDER THE DIRECTION OF R. W. SKAGGS.

*****************************************************************************


                    *******************
                    * D R A I N M O D *
                    *******************

 DATA READ FROM INPUT FILE: D:\DM40\INPUT40\20CONT40.LIS

                         TITLE OF RUN
                         ************


Stephen Broughton  Masters Thesis 91/11/05- Controlled Drainage-weir 40 cm

Drain spacing = 20 meters - Soybean on Sandy Loam

                        CLIMATE INPUTS
                        ******* ******

     DESCRIPTION                                (VARIABLE)      VALUE    UNIT
------------------------------------------------------------------------------
FILE FOR RAINDATA ..............................................  D:\DM40\WEAT
FILE FOR TEMPERATURE/PET DATA ..................................  D:\DM40\WEAT
RAINFALL STATION NUMBER.........................(RAINID)       725250
TEMPERATURE/PET STATION NUMBER..................(TEMPID)       725250
STARTING YEAR OF SIMULATION.................(START YEAR)        1960    YEAR
STARTING MONTH OF SIMULATION...............(START MONTH)           3    MONTH
ENDING YEAR OF SIMULATION.....................(END YEAR)        1983    YEAR
ENDING MONTH OF SIMULATION...................(END MONTH)          12    MONTH
TEMPERATURE STATION LATITUDE..................(TEMP LAT)       45.35    DEG.MIN
HEAT INDEX.........................................(HID)       35.00


ET MULTIPLICATION FACTOR FOR EACH MONTH
    .79    .81  1.02  1.13  1.29  1.31  1.32  1.22  1.04   .94   .79   .74
```

DRAINAGE SYSTEM DESIGN
****

*** CONTROLLED DRAINAGE ***

JOB TITLE:

Stephen Broughton Masters Thesis 91/11/05- Controlled Drain
Drain spacing = 20 meters - Soybean on Sandy Loam

```
              STMAX = 1.50 CM                       SOIL SURFACE
+     __/)______________________________________________________/)__
          :                                         :
          :                                         :
          :                                         :
          :                                         :
          :                                         :
      ADEPTH =110. CM                          DDRAIN =100. CM
          :                                         :
          :                                         :
          :    O-------------SDRAIN = 2000. CM -----------O  -
          :    \                                    :
          : EFFRAD = .51 CM                         :
          :                                    HDRAIN = 10. CM
          :                                         :
          :                                         :
      - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          :
          :
          :
          :                                 IMPERMEABLE LAYER
+
      ////////////////////////////////////////////////////////////
```

DEPTH (CM)	SATURATED HYDRAULIC CONDUCTIVITY (CM/HR)
.0 - 1.0	9.500

DEPTH TO DRAIN = 100.0 CM
EFFECTIVE DEPTH FROM DRAIN TO IMPERMEABLE LAYER = 9.6 CM
DISTANCE BETWEEN DRAINS = 2000.0 CM
MAXIMUM DEPTH OF SURFACE PONDING = 1.50 CM
EFFECTIVE DEPTH TO IMPERMEABLE LAYER = 109.6 CM
DRAINAGE COEFFICIENT(AS LIMITED BY SUBSURFACE OUTLET) = 1.00 CM/DAY
ACTUAL DEPTH FROM SURFACE TO IMPERMEABLE LAYER = 110.0 CM
SURFACE STORAGE THAT MUST BE FILLED BEFORE WATER
  CAN MOVE TO DRAIN = .50 CM
FACTOR -G- IN KIRKHAM EQ. 2-17 =15.05

*** SEEPAGE LOSS INPUTS ***

No seepage due to field slope

No seepage due to vertical deep seepage

No seepage due to lateral deep seepage

*** end of seepage inputs ***

WIDTH OF DITCH BOTTOM = 100.0 CM
SIDE SLOPE OF DITCH (HORIZ:VERT) = 2.50 : 1.00

INITIAL WATER TABLE DEPTH = .0 CM

DEPTH OF WEIR FROM THE SURFACE

DATE	1/ 1	2/ 1	3/ 1	4/ 1	5/ 1	6/ 1
WEIR DEPTH	100.0	100.0	100.0	100.0	40.0	40.0

DATE	7/ 1	8/ 1	9/ 1	10/ 1	11/ 1	12/ 1
WEIR DEPTH	40.0	40.0	40.0	100.0	100.0	100.0

SOIL INPUTS
****

TABLE 1
DRAINAGE TABLE

VOID VOLUME (CM)	WATER TABLE DEPTH (CM)
.0	.0
1.0	45.3
2.0	70.7
3.0	97.3
4.0	108.4
5.0	117.6
6.0	126.9
7.0	136.2
8.0	145.5
9.0	154.8
10.0	164.1
11.0	173.4
12.0	182.7
13.0	192.0
14.0	201.2
15.0	210.5
16.0	219.8
17.0	229.1
18.0	238.4
19.0	247.7
20.0	257.0
21.0	266.3

TABLE 1 (CONTINUED) DRAINAGE TABLE

VOID VOLUME (CM)	WATER TABLE DEPTH (CM)
22.0	275.5
23.0	284.8
24.0	294.1
25.0	303.4
26.0	312.7
27.0	322.0
28.0	331.3
29.0	340.6
30.0	349.8
35.0	396.3
40.0	442.7
45.0	489.2
50.0	535.6
60.0	628.5
70.0	721.4
80.0	814.2
90.0	907.1

TABLE 2

SOIL WATER CHARACTERISTIC VS VOID VOLUME VS UPFLUX

HEAD (CM)	WATER CONTENT (CM/CM)	VOID VOLUME (CM)	UPFLUX (CM/HR)
.0	.5900	.00	.2000
10.0	.5600	.09	.1500
20.0	.5000	.17	.1000
30.0	.4500	.42	.1000
40.0	.4100	.80	.0530
50.0	.3700	1.18	.0060
60.0	.3500	1.58	.0047
70.0	.3300	1.97	.0033
80.0	.3200	2.37	.0020
90.0	.3050	2.73	.0015
100.0	.2900	3.10	.0010
110.0	.2800	4.18	.0010
120.0	.2733	5.25	.0010
130.0	.2667	6.33	.0010
140.0	.2600	7.41	.0010
150.0	.2533	8.48	.0009
160.0	.2467	9.56	.0009
170.0	.2400	10.64	.0009
180.0	.2333	11.71	.0009
190.0	.2267	12.79	.0009
200.0	.2200	13.87	.0009
210.0	.2170	14.94	.0009
220.0	.2140	16.02	.0009
230.0	.2110	17.10	.0009
240.0	.2080	18.17	.0008
250.0	.2050	19.25	.0008
260.0	.2020	20.33	.0008
270.0	.1990	21.40	.0008
280.0	.1960	22.48	.0008
290.0	.1930	23.56	.0008
300.0	.1900	24.63	.0008
350.0	.1850	30.02	.0007
400.0	.1800	35.40	.0007
450.0	.1750	40.78	.0006
500.0	.1700	46.17	.0006
600.0	.1675	56.93	.0004
700.0	.1650	67.70	.0003
800.0	.1625	78.47	.0002
900.0	.1600	89.23	.0001

GREEN AMPT INFILTRATION PARAMETERS

W.T.D. (CM)	A (CM)	B (CM)
.000	.000	.000
50.000	1.240	2.250
80.000	1.470	1.740
100.000	1.470	1.470
160.000	1.580	1.140
200.000	1.580	1.000
250.000	1.590	.900
300.000	1.590	.830
500.000	1.600	.690
1000.000	1.640	.580

TRAFFICABILITY

REQUIREMENTS	FIRST PERIOD	SECOND PERIOD
-MINIMUM AIR VOLUME IN SOIL (CM):	3.00	3.00
-MAXIMUM ALLOWABLE DAILY RAINFALL (CM):	1.00	1.00
-MINIMUM TIME AFTER RAIN BEFORE TILLING CAN CONTINUE:	2.00	2.00
WORKING TIMES		
-DATE TO BEGIN COUNTING WORK DAYS:	5/ 1	9/15
-DATE TO STOP COUNTING WORK DAYS:	6/15	11/15
-FIRST WORK HOUR OF THE DAY:	8	7
-LAST WORK HOUR OF THE DAY:	21	20

CROP

SOIL MOISTURE AT CROP WILTING POINT = .30

HIGH WATER STRESS: BEGIN STRESS PERIOD ON 4/15
END STRESS PERIOD ON 10/15
CROP IS IN STRESS WHEN WATER TABLE IS ABOVE 30.0 CM

DROUGHT STRESS: BEGIN STRESS PERIOD ON 4/15
END STRESS PERIOD ON 10/15

MO	DAY	ROOTING DEPTH (CM)
1	1	3.0
5	25	3.0
6	15	7.0
6	30	15.0
7	15	30.0
7	30	30.0
8	15	30.0
8	30	28.0
9	30	25.0
12	31	3.0

WASTEWATER IRRIGATION

NO WASTEWATER IRRIGATION SCHEDULED:

YIELD INPUTS

```
                              YIELD INPUTS
                              ************

last planting day without yield loss  (JLAST) :         137
length of growing season (IGROW)              :         125
1st planting day reduction factor (PDRF)      :   5.000000E-01
days using 1st planting delay fact (DELAY1)   :     30.000000
2nd planting day reduction factor (PDRF2)     :   8.000000E-01
total days of work before planting (REQWRK)   :      8.000000
IOW:          30
IOH:           3
SI :   0.000000E+00
D  :   0.000000E+00
E  :   0.000000E+00
FO :   0.000000E+00
YI :     100.000000
SF :       1.500000
YRMAX :   0.000000E+00
YSLOPE:        1.220000
YRDMAX:      103.000000
DSLOPE:   4.200000E-01
PD :          125
IGR:          125
SDF:            1
IPS(I),IPE(I),CSD(I),I=1,IOH
   0   42        .5100
  43   80        .3300
  81  125        .0200
CSI(I),I=1,IOW
          .0000       .0000       .0000      1.0000      1.0000
         1.0000      1.0000      1.0000      1.0000      1.0000
         1.0000      1.0000      1.0000      1.0000      1.0000
         1.0000      1.0000      1.0000      1.0000       .5000
          .5000       .0000       .0000       .0000       .0000
          .0000       .0000       .0000       .0000       .0000


******************************* END OF INPUTS *******************************

 ----------RUN STATISTICS ----------        time: 12/10/1991  @ 10: 2
input file:    D:\DM40\INPUT40\20CONT40.LIS
parameters:      controlled drainage      and yields calculated
                 drain spacing =    2000. cm   drain depth =   100.0 cm
-------------------------------------------------------------------------


**> Total simulation time=  11.976 minutes.
```

Appendix E

Drainmod 4.0 Simulation Results

Table E1 Drainmod results for a Controlled Drainage run with 20 meter drain spacing and 40 cm weir depth.

	SDI - STRESS		plant	plant	harv.	RELATIVE YIELDS (%)			
	excess	drought	date	delay	date	excess	drought	delay	overall
1960	.0	28.8	132	0.	257	100.0	64.9	100.0	64.9
1961	.1	22.0	134	0.	259	100.0	73.2	100.0	73.2
1962	.0	24.7	133	0.	258	100.0	69.9	100.0	69.9
1963	.0	25.0	132	0.	257	100.0	69.5	100.0	69.5
1964	.0	49.1	132	0.	257	100.0	40.1	100.0	40.1
1965	.0	42.2	132	0.	257	100.0	48.5	100.0	48.5
1966	.0	46.3	132	0.	257	100.0	43.5	100.0	43.5
1967	10.3	40.3	137	0.	262	98.7	50.9	100.0	50.2
1968	.0	42.5	132	0.	257	100.0	48.2	100.0	48.2
1969	.7	27.4	132	0.	257	100.0	66.6	100.0	66.6
1970	.0	64.8	132	0.	257	100.0	20.9	100.0	20.9
1971	.0	59.2	132	0.	257	100.0	27.8	100.0	27.8
1972	.2	2.0	134	0.	259	100.0	97.5	100.0	97.5
1973	.0	32.0	132	0.	257	100.0	61.0	100.0	61.0
1974	.0	15.8	143	6.	268	100.0	80.7	97.0	78.3
1975	.0	28.3	132	0.	257	100.0	65.5	100.0	65.5
1976	.0	21.0	132	0.	257	100.0	74.3	100.0	74.3
1977	.0	24.6	132	0.	257	100.0	70.0	100.0	70.0
1978	.0	49.5	132	0.	257	100.0	39.6	100.0	39.6
1979	.0	56.9	134	0.	259	100.0	30.6	100.0	30.6
1980	.0	24.0	132	0.	257	100.0	70.7	100.0	70.7
1981	.0	15.5	132	0.	257	100.0	81.1	100.0	81.1
1982	.0	62.2	132	0.	257	100.0	24.1	100.0	24.1
1983	.5	56.3	140	3.	265	100.0	31.4	98.5	30.9
AVG	.5	35.9	133.	0.	258.	99.9	56.3	99.8	56.1

Table E2 Drainmod results for a Controlled Drainage run with 20 meter drain spacing and 60 cm weir depth.

	SDI - STRESS		plant	plant	harv.	RELATIVE YIELDS (%)			
	excess	drought	date	delay	date	excess	drought	delay	overall
1960	.0	28.8	132	0.	257	100.0	64.9	100.0	64.9
1961	.1	22.0	134	0.	259	100.0	73.2	100.0	73.2
1962	.0	24.7	133	0.	258	100.0	69.9	100.0	69.9
1963	.0	25.0	132	0.	257	100.0	69.5	100.0	69.5
1964	.0	49.1	132	0.	257	100.0	40.1	100.0	40.1
1965	.0	42.2	132	0.	257	100.0	48.5	100.0	48.5
1966	.0	46.3	132	0.	257	100.0	43.5	100.0	43.5
1967	10.3	40.3	137	0.	262	98.7	50.9	100.0	50.2
1968	.0	42.5	132	0.	257	100.0	48.2	100.0	48.2
1969	.7	27.4	132	0.	257	100.0	66.6	100.0	66.6
1970	.0	64.8	132	0.	257	100.0	20.9	100.0	20.9
1971	.0	59.2	132	0.	257	100.0	27.8	100.0	27.8
1972	.2	2.0	134	0.	259	100.0	97.5	100.0	97.5
1973	.0	32.0	132	0.	257	100.0	61.0	100.0	61.0
1974	.0	19.4	143	6.	268	100.0	76.4	97.0	74.1
1975	.0	28.3	132	0.	257	100.0	65.5	100.0	65.5
1976	.0	21.0	132	0.	257	100.0	74.3	100.0	74.3
1977	.0	24.6	132	0.	257	100.0	70.0	100.0	70.0
1978	.0	49.5	132	0.	257	100.0	39.6	100.0	39.6
1979	.0	56.9	134	0.	259	100.0	30.6	100.0	30.6
1980	.0	24.0	132	0.	257	100.0	70.7	100.0	70.7
1981	.0	15.5	132	0.	257	100.0	81.1	100.0	81.1
1982	.0	62.2	132	0.	257	100.0	24.1	100.0	24.1
1983	.5	56.3	140	3.	265	100.0	31.4	98.5	30.9
AVG	.5	36.0	133.	0.	258.	99.9	56.1	99.8	55.9

Table E3 **Drainmod results for a Controlled Drainage run with 20 meter drain spacing and 80 cm weir depth.**

	SDI - STRESS excess	SDI - STRESS drought	plant date	plant delay	harv. date	RELATIVE YIELDS (%) excess	RELATIVE YIELDS (%) drought	RELATIVE YIELDS (%) delay	RELATIVE YIELDS (%) overall
1960	.0	28.8	132	0.	257	100.0	64.9	100.0	64.9
1961	.0	26.4	134	0.	259	100.0	67.8	100.0	67.8
1962	.0	24.7	133	0.	258	100.0	69.9	100.0	69.9
1963	.0	25.0	132	0.	257	100.0	69.5	100.0	69.5
1964	.0	49.1	132	0.	257	100.0	40.1	100.0	40.1
1965	.0	42.2	132	0.	257	100.0	48.5	100.0	48.5
1966	.0	46.3	132	0.	257	100.0	43.5	100.0	43.5
1967	10.3	44.0	137	0.	262	98.7	46.3	100.0	45.7
1968	.0	42.5	132	0.	257	100.0	48.2	100.0	48.2
1969	.7	27.7	132	0.	257	100.0	66.2	100.0	66.2
1970	.0	64.8	132	0.	257	100.0	20.9	100.0	20.9
1971	.0	59.2	132	0.	257	100.0	27.8	100.0	27.8
1972	.0	2.6	134	0.	259	100.0	96.8	100.0	96.8
1973	.0	37.4	132	0.	257	100.0	54.4	100.0	54.4
1974	.0	28.4	143	6.	268	100.0	65.3	97.0	63.3
1975	.0	28.3	132	0.	257	100.0	65.5	100.0	65.5
1976	.0	21.0	132	0.	257	100.0	74.3	100.0	74.3
1977	.0	24.6	132	0.	257	100.0	70.0	100.0	70.0
1978	.0	49.5	132	0.	257	100.0	39.6	100.0	39.6
1979	.0	56.9	134	0.	259	100.0	30.6	100.0	30.6
1980	.0	24.0	132	0.	257	100.0	70.7	100.0	70.7
1981	.0	15.7	132	0.	257	100.0	80.8	100.0	80.8
1982	.0	62.2	132	0.	257	100.0	24.1	100.0	24.1
1983	.0	62.4	140	3.	265	100.0	23.9	98.5	23.5
AVG	.5	37.2	133.	0.	258.	99.9	54.6	99.8	54.4

Table E4 **Drainmod results for a Controlled Drainage run with 20 meter drain spacing and 100 cm weir depth.**

	SDI - STRESS excess	SDI - STRESS drought	plant date	plant delay	harv. date	RELATIVE YIELDS (%) excess	RELATIVE YIELDS (%) drought	RELATIVE YIELDS (%) delay	RELATIVE YIELDS (%) overall
1960	.0	29.0	132	0.	257	100.0	64.6	100.0	64.6
1961	.0	29.6	134	0.	259	100.0	63.8	100.0	63.8
1962	.0	25.7	133	0.	258	100.0	63.7	100.0	68.7
1963	.0	26.7	132	0.	257	100.0	67.4	100.0	67.4
1964	.0	49.1	132	0.	257	100.0	40.1	100.0	40.1
1965	.0	42.2	132	0.	257	100.0	48.5	100.0	48.5
1966	.0	46.9	132	0.	257	100.0	42.7	100.0	42.7
1967	1.1	49.0	136	0.	261	100.0	40.2	100.0	40.2
1968	.0	42.8	132	0.	257	100.0	47.8	100.0	47.8
1969	.7	30.1	132	0.	257	100.0	63.3	100.0	63.3
1970	.0	65.0	132	0.	257	100.0	20.7	100.0	20.7
1971	.0	59.8	132	0.	257	100.0	27.0	100.0	27.0
1972	.0	3.2	134	0.	259	100.0	96.1	100.0	96.1
1973	.0	42.0	132	0.	257	100.0	48.8	100.0	48.8
1974	.0	29.6	143	6.	268	100.0	63.8	97.0	61.9
1975	.0	28.3	132	0.	257	100.0	65.5	100.0	65.5
1976	.0	22.9	132	0.	257	100.0	72.0	100.0	72.0
1977	.0	24.6	132	0.	257	100.0	69.9	100.0	69.9
1978	.0	49.5	132	0.	257	100.0	39.6	100.0	39.6
1979	.0	60.6	134	0.	259	100.0	26.1	100.0	26.1
1980	.0	25.3	132	0.	257	100.0	69.1	100.0	69.1
1981	.0	18.0	132	0.	257	100.0	78.0	100.0	78.0
1982	.0	62.2	132	0.	257	100.0	24.2	100.0	24.2
1983	.0	66.5	140	3.	265	100.0	18.9	98.5	18.6
AVG	.1	38.7	133.	0.	258.	100.0	52.8	99.8	52.7

Table E5 **Drainmod results for a Subirrigation run with 20 meter drain spacing and 40 cm weir depth.**

	SDI - STRESS excess	SDI - STRESS drought	plant date	plant delay	harv. date	RELATIVE YIELDS (%) excess	drought	delay	overall
1960	38.9	.1	132	0.	257	86.7	99.8	100.0	86.5
1961	44.9	.0	134	0.	259	84.1	100.0	100.0	84.1
1962	31.0	.7	133	0.	258	90.0	99.2	100.0	89.3
1963	40.1	.0	132	0.	257	86.1	100.0	100.0	86.1
1964	1.4	.0	132	0.	257	100.0	100.0	100.0	100.0
1965	5.2	.0	132	0.	257	100.0	100.0	100.0	100.0
1966	23.6	.2	132	0.	257	93.1	99.7	100.0	92.9
1967	52.6	.2	137	0.	262	80.9	99.8	100.0	80.7
1968	10.1	.0	132	0.	257	98.8	100.0	100.0	98.8
1969	56.4	.0	132	0.	257	79.3	100.0	100.0	79.3
1970	3.7	.0	132	0.	257	100.0	100.0	100.0	100.0
1971	1.5	.0	132	0.	257	100.0	100.0	100.0	100.0
1972	96.2	.2	134	0.	259	62.6	99.7	100.0	62.4
1973	49.7	.0	132	0.	257	82.1	100.0	100.0	82.1
1974	30.0	.0	143	6.	268	90.4	100.0	97.0	87.7
1975	37.8	.3	132	0.	257	87.1	99.6	100.0	86.8
1976	47.4	.0	132	0.	257	83.1	100.0	100.0	83.1
1977	27.9	.0	132	0.	257	91.3	100.0	100.0	91.3
1978	22.8	1.2	132	0.	257	93.4	98.6	100.0	92.1
1979	15.2	.0	134	0.	259	96.6	100.0	100.0	96.6
1980	55.9	.0	132	0.	257	79.5	100.0	100.0	79.5
1981	29.9	.0	132	0.	257	90.4	100.0	100.0	90.4
1982	12.2	.4	132	0.	257	97.9	99.5	100.0	97.4
1983	32.6	.0	140	3.	265	89.3	100.0	98.5	87.9
AVG	32.0	.1	133.	0.	258.	89.3	99.8	99.8	89.0

Table E6 **Drainmod results for a Subirrigation run with 20 meter drain spacing and 60 cm weir depth.**

	SDI - STRESS excess	SDI - STRESS drought	plant date	plant delay	harv. date	RELATIVE YIELDS (%) excess	drought	delay	overall
1960	8.8	18.4	132	0.	257	99.3	77.5	100.0	77.0
1961	7.1	.9	134	0.	259	100.0	96.8	100.0	98.8
1962	.0	13.7	133	0.	258	100.0	83.3	100.0	83.3
1963	13.0	5.0	132	0.	257	97.6	93.9	100.0	91.6
1964	.0	13.5	132	0.	257	100.0	83.5	100.0	83.5
1965	1.0	16.1	132	0.	257	100.0	80.3	100.0	80.3
1966	.1	13.8	132	0.	257	100.0	83.2	100.0	83.2
1967	33.5	4.6	137	0.	262	88.9	94.4	100.0	83.9
1968	.0	6.0	132	0.	257	100.0	92.7	100.0	92.7
1969	26.3	2.5	132	0.	257	91.9	96.9	100.0	89.1
1970	.6	20.4	132	0.	257	100.0	75.1	100.0	75.1
1971	.0	14.7	132	0.	257	100.0	82.0	100.0	82.0
1972	16.7	1.2	134	0.	259	96.0	98.5	100.0	94.6
1973	1.7	4.6	132	0.	257	100.0	94.3	100.0	94.3
1974	.0	2.1	143	6.	268	100.0	97.4	97.0	94.5
1975	.0	4.7	132	0.	257	100.0	94.3	100.0	94.3
1976	14.6	3.4	132	0.	257	96.9	95.9	100.0	92.9
1977	.3	3.6	132	0.	257	100.0	95.6	100.0	95.6
1978	.0	7.0	132	0.	257	100.0	91.5	100.0	91.5
1979	1.0	15.3	134	0.	259	100.0	81.3	100.0	81.3
1980	13.1	11.7	132	0.	257	97.5	85.8	100.0	83.6
1981	.6	1.7	132	0.	257	100.0	97.9	100.0	97.9
1982	.0	13.7	132	0.	257	100.0	83.3	100.0	83.3
1983	14.6	14.5	140	3.	265	96.9	82.3	98.5	78.5
AVG	6.4	8.9	133.	0.	258.	98.5	89.2	99.8	87.6

Table E7 Drainmod results for a Subirrigation run with 20 meter drain spacing and 80 cm weir depth.

	SDI - STRESS excess	SDI - STRESS drought	plant date	plant delay	harv. date	RELATIVE YIELDS (%) excess	RELATIVE YIELDS (%) drought	RELATIVE YIELDS (%) delay	RELATIVE YIELDS (%) overall
1960	.3	24.7	132	0.	257	100.0	69.9	100.0	69.9
1961	.0	17.9	134	0.	259	100.0	78.2	100.0	78.2
1962	.0	17.6	133	0.	258	100.0	78.6	100.0	78.6
1963	5.1	15.5	132	0.	257	100.0	81.1	100.0	81.1
1964	.0	31.3	132	0.	257	100.0	61.8	100.0	61.8
1965	.2	25.9	132	0.	257	100.0	68.4	100.0	68.4
1966	.0	33.4	132	0.	257	100.0	59.2	100.0	59.2
1967	14.5	30.9	137	0.	262	96.9	62.3	100.0	60.4
1968	.0	24.7	132	0.	257	100.0	69.9	100.0	69.9
1969	12.5	16.3	132	0.	257	97.7	80.1	100.0	78.2
1970	.0	45.9	132	0.	257	100.0	44.1	100.0	44.1
1971	.0	41.2	132	0.	257	100.0	49.7	100.0	49.7
1972	1.8	2.5	134	0.	259	100.0	96.9	100.0	96.9
1973	.0	26.7	132	0.	257	100.0	67.4	100.0	67.4
1974	.0	11.5	143	6.	268	100.0	86.0	97.0	83.4
1975	.0	8.8	132	0.	257	100.0	89.3	100.0	89.3
1976	.1	7.0	132	0.	257	100.0	91.4	100.0	91.4
1977	.0	7.3	132	0.	257	100.0	91.1	100.0	91.1
1978	.0	31.5	132	0.	257	100.0	61.5	100.0	61.5
1979	.1	41.0	134	0.	259	100.0	50.0	100.0	50.0
1980	.0	17.3	132	0.	257	100.0	78.8	100.0	78.8
1981	.0	6.0	132	0.	257	100.0	92.7	100.0	92.7
1982	.0	43.3	132	0.	257	100.0	47.2	100.0	47.2
1983	.1	46.8	140	3.	265	100.0	42.9	98.5	42.3
AVG	1.4	24.0	133.	0.	258.	99.8	70.8	99.8	70.5

Appendix F

Weather Data

Class A Evaporataion Pan

1989 and 1990 Growing Seasons

Table F1 **June 1989 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water		Rain	Net loss	Accum	Daily	Water Temperature			Air Temperature			
	Add (mm)	Remove (mm)	guage (mm)	from Pan (mm)	Wind (km)	Wind (km)	Max (C)	Min (C)	Avg (C)	Max (C)	Min (C)	Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
19					3526								
20	0.5	0.0	0.6	1.1	3564	38	25.0	13.0	19.0	25.0	19.0	22.0	
21	6.2	0.0	0.0	6.2	3633	69	33.5	22.5	28.0	27.0	19.0	23.0	
22	7.2	0.0	0.0	7.2	3697	64	35.5	22.5	29.0	31.0	20.0	25.5	
23	7.2	0.0	0.0	7.2	3764	67	37.0	21.0	29.0	33.0	22.0	27.5	
24	6.0	0.0	0.0	6.0	3858	94	33.0	18.0	25.5	27.0	16.0	21.5	
25	5.4	0.0	0.0	5.4	3896	38	34.0	20.0	27.0	26.0	19.0	22.5	
26	4.8	0.0	0.0	4.8	3932	36	31.0	21.0	26.0	26.5	18.5	22.5	
27	6.0	0.0	0.1	6.1	4026	94	31.5	20.5	26.0	30.0	20.0	25.0	
28	2.8	0.0	4.5	7.3	4143	117	32.5	13.0	22.8	23.5	13.0	18.3	
29	7.2	0.0	0.0	7.2	4221	78	28.0	13.5	20.8	23.0	13.0	18.0	
30	7.2	0.0	0.0	7.2	4277	56	30.0	16.5	23.3	26.0	15.0	20.5	
Averages				6.0		68.3	31.9	18.3	25.1	27.1	17.7	22.4	

Table F2 **July 1989 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water Add (mm)	Water Remove (mm)	Rain guage (mm)	Net loss from Pan (mm)	Accum Wind (km)	Daily Wind (km)	Water Temperature Max (C)	Water Temperature Min (C)	Water Temperature Avg (C)	Air Temperature Max (C)	Air Temperature Min (C)	Air Temperature Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
					4277								
1	1.0	0.0	1.6	2.6	4345	68	22.0	17.0	19.5	21.5	15.0	18.3	
2	5.2	0.0	0.0	5.2	4418	73	32.5	19.0	25.8	31.0	16.0	23.5	
3	7.0	0.0	0.0	7.0	4470	52	34.5	20.0	27.3	30.0	19.0	24.5	
4	6.2	0.0	0.0	6.2	4534	64	34.5	20.5	27.5	30.0	24.0	27.0	
5	4.4	0.0	0.0	4.4	4598	64	32.0	20.5	26.3	31.5	18.0	24.8	
6	4.6	0.0	3.2	7.8	4672	74	35.5	21.5	28.5	31.0	21.0	26.0	
7	6.8	0.0	0.0	6.8	4761	89	33.0	15.5	24.3	27.0	13.0	20.0	
8	7.2	0.0	0.0	7.2	4819	58	30.5	17.0	23.8	26.0	15.0	20.5	
9	0.0	10.4	16.6	6.2	4893	74	30.0	18.5	24.3	26.5	17.0	21.8	
10	0.0	7.2	12.8	5.6	4979	86	27.0	17.0	22.0	26.5	16.0	21.3	
11	2.8	0.0	2.1	4.9	5059	80	27.0	16.0	21.5	25.0	16.0	20.5	
12	6.6	0.0	0.0	6.6	5111	52	31.0	17.5	24.3	26.5	16.0	21.3	
13	2.4	0.0	2.3	4.7	5166	55	29.5	16.0	22.8	26.0	15.0	20.5	
14	5.0	0.0	0.0	5.0	5209	43	29.0	15.0	22.0	25.0	11.0	18.0	
15	7.0	0.0	0.0	7.0	5246	37	31.0	15.5	23.3	25.0	13.0	19.0	
16	5.2	0.0	0.0	5.2	5277	31	31.0	15.5	23.3	27.0	11.5	19.3	
17	6.4	0.0	0.0	6.4	5315	38	32.5	17.0	24.8	26.5	15.0	20.8	
18	5.8	0.0	0.0	5.8	5377	62	31.5	17.0	24.3	27.0	16.0	21.5	
19	7.2	0.0	0.0	7.2	5432	55	31.5	16.0	23.8	26.5	13.5	20.0	
20	5.8	0.0	0.0	5.8	5517	85	30.0	13.0	21.5	26.5	12.0	19.3	
21	4.8	0.0	0.0	4.8	5572	55	31.5	15.5	23.5	26.0	15.0	20.5	
22	7.6	0.0	0.0	7.6	5616	44	33.0	19.0	26.0	31.0	18.0	24.5	
23	4.8	0.0	0.0	4.8	5657	41	33.5	19.0	26.3	31.5	20.5	26.0	
24	4.6	0.0	0.0	4.6	5712	55	34.0	20.0	27.0	33.0	22.5	27.8	
25	6.6	0.0	0.0	6.6	5780	68	35.0	20.0	27.5	33.0	21.0	27.0	
26	7.2	0.0	0.0	7.2	5842	62	34.5	21.0	27.8	35.0	23.0	29.0	
27	0.0	3.7	7.2	3.5	5924	82	34.5	19.0	26.8	26.5	19.0	22.8	
28	6.0	0.0	0.0	6.0	6024	100	24.0	10.5	17.3	24.0	12.5	18.3	
29	4.6	0.0	0.0	4.6	6079	55	27.0	11.5	19.3	24.0	13.0	18.5	
30	4.4	0.0	0.0	4.4	6142	63	28.0	14.0	21.0	26.0	14.0	20.0	
31	5.6	0.0	0.0	5.6	6196	54	31.5	16.0	23.8	26.0	12.0	19.0	
Average				5.7		61.9	31.0	17.1	24.1	27.7	16.2	22.0	

Table F3 **August 1989 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water		Rain	Net loss	Accum	Daily	Water Temperature			Air Temperature			
	Add (mm)	Remove (mm)	guage (mm)	from Pan (mm)	Wind (km)	Wind (km)	Max (C)	Min (C)	Avg (C)	Max (C)	Min (C)	Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
	5.8				6196		31.5	16.0		26.0	12.0		
1	7.2	0.0	0.0	7.2	6260	64	32.5	17.0	24.8	29.5	20.5	25.0	
2	0.0	2.4	3.8	1.4	6313	53	25.5	17.0	21.3	25.0	19.0	22.0	
3	0.0	7.2	13.1	5.9	6393	80	33.0	18.0	25.5	30.0	19.0	24.5	
4	0.0	28.2	32.0	3.8	6441	48	28.5	20.5	24.5	27.0	22.0	24.5	
5	7.2	0.0	0.0	7.2	6491	50	34.0	20.0	27.0	30.0	21.5	25.8	
6	4.0	0.0	1.8	5.8	6570	79	33.0	14.5	23.8	31.0	15.0	23.0	
7	4.0	0.0	0.0	4.0	6634	64	25.5	9.5	17.5	19.0	11.0	15.0	
8	2.4	0.0	0.0	2.4	6695	61	23.5	12.5	18.0	19.0	11.0	15.0	
9	6.2	0.0	0.0	6.2	6743	48	28.0	11.0	19.5	24.0	14.0	19.0	
10	4.8	0.0	0.0	4.8	6785	42	30.5	16.5	23.5	26.0	14.0	20.0	
11	3.6	0.0	0.6	4.2	6868	83	30.5	17.0	23.8	26.0	18.0	22.0	
12	3.4	0.0	0.4	3.8	6929	61	26.5	18.5	22.5	23.0	19.0	21.0	
13	3.0	0.0	0.4	3.4	6963	34	30.0	18.5	24.3	26.0	19.0	22.5	
14	4.8	0.0	0.0	4.8	7007	44	32.0	17.5	24.8	26.0	16.0	21.0	
15	4.3	0.0	1.0	5.3	7093	86	31.5	18.0	24.8	26.5	20.0	23.3	
16	5.2	0.0	0.6	5.8	7147	54	29.0	14.5	21.8	24.0	13.0	18.5	
17	5.5	0.0	0.0	5.5	7197	50	29.0	12.0	20.5	23.0	10.0	16.5	
18	4.8	0.0	0.0	4.8	7238	41	28.5	13.0	20.8	26.0	10.0	18.0	
19	0.0	7.2	12.6	5.4	7285	47	30.0	16.0	23.0	27.0	17.0	22.0	
20	0.0	6.8	8.3	1.5	7337	52	23.0	17.0	20.0	23.0	18.0	20.5	
21	4.8	0.0	0.0	4.8	7408	71	28.5	13.5	21.0	26.0	15.0	20.5	
22	1.7	0.0	2.0	3.7	7457	49	27.5	15.0	21.3	23.0	17.0	20.0	
23	3.4	0.0	0.0	3.4	7538	81	24.0	11.0	17.5	24.0	12.0	18.0	
24	4.8	0.0	0.0	4.8	7610	72	25.5	7.0	16.3	19.0	3.0	11.0	
25	4.8	0.0	0.0	4.8	7681	71	24.0	8.5	16.3	19.0	9.0	14.0	
26	5.0	0.0	0.0	5.0	7732	51	25.0	8.0	16.5	20.0	10.0	15.0	
27	3.8	0.0	0.2	4.0	7762	30	26.0	8.0	17.0	23.0	11.5	17.3	
28	3.8	0.0	0.0	3.8	7796	34	29.0	8.0	18.5	26.0	15.0	20.5	
29	0.9	0.0	0.0	0.9	7847	51	25.0	17.0	21.0	25.0	20.0	22.5	
30	5.8	0.0	0.0	5.8	7979	132	26.5	9.5	18.0	24.0	12.5	18.3	
31	3.6	0.0	0.6	4.2	8044	65	24.5	11.5	18.0	22.0	15.0	18.5	
average				4.5		59.6	28.0	14.0	21.0	24.6	15.1	19.8	

Table F4 **September 1989 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

Sept	Water Add (mm)	Water Remove (mm)	Rain guage (mm)	Net loss from Pan (mm)	Accum Wind (km)	Daily Wind (km)	Water Temperature Max (C)	Water Temperature Min (C)	Water Temperature Avg (C)	Air Temperature Max (C)	Air Temperature Min (C)	Air Temperature Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
31	3.6	0.0	0.6	4.2	8044	8044	24.5	11.5	18.0	22.0	15.0	18.5	
1	0.0	12.5	14.8	2.3	8118	74	24.5	11.5	18.0	23.0	14.0	18.5	
2	4.8	0.0	0.0	4.8	8178	60	26.0	9.5	17.8	21.0	7.0	14.0	
3	5.0	0.0	0.1	5.1	8214	36	25.0	8.5	16.8	20.0	6.0	13.0	
4	2.9	0.0	0.0	2.9	8261	47	26.0	10.5	18.3	23.0	10.0	16.5	
5	3.4	0.0	0.0	3.4	8349	88	23.0	6.0	14.5	22.0	14.0	18.0	
6	2.8	0.0	0.0	2.8	8394	45	28.0	13.0	20.5	27.0	14.0	20.5	
7	3.6	0.0	0.0	3.6	8428	34	30.0	17.0	23.5	26.0	15.0	20.5	
8	3.2	0.0	0.0	3.2	8462	34	27.0	18.0	22.5	26.0	21.0	23.5	
9	2.8	0.0	0.0	2.8	8509	47	29.0	19.5	24.3	26.5	20.0	23.3	
10	6.1	0.0	0.0	6.1	8605	96	30.0	14.5	22.3	26.5	16.0	21.3	
11	1.4	0.0	0.0	1.4	8634	29	22.0	13.0	17.5	20.0	12.0	16.0	
12	3.6	0.0	0.0	3.6	8686	52	27.5	13.0	20.3	24.0	14.0	19.0	
13	0.0	1.4	3.4	2.0	8724	38	24.0	13.5	18.8	21.0	12.0	16.5	
14	0.0	14.4	16.9	2.5	8786	62	18.5	13.0	15.8	16.5	12.5	14.5	
15	2.4	0.0	0.2	2.6	8825	39	25.0	11.5	18.3	20.5	8.0	14.3	
16	0.0	1.0	3.1	2.1	8964	139	20.0	13.0	16.5	19.0	12.5	15.8	
17	1.2	0.0	0.2	1.4	9001	37	16.0	11.0	13.5	16.0	11.0	13.5	
18	2.4	0.0	0.2	2.6	9059	58	25.0	11.0	18.0	22.5	11.0	16.8	
19	0.0	2.4	4.2	1.8	9172	113	21.0	14.5	17.8	20.0	11.0	15.5	
20	1.6	0.0	0.4	2.0	9219	47	24.5	16.0	20.3	23.0	15.0	19.0	
21	1.4	0.0	1.4	2.8	9253	34	27.0	16.5	21.8	25.0	12.0	18.5	
22	0.0	6.8	10.1	3.3	9408	155	28.0	16.5	22.3	26.0	11.0	18.5	
23	3.3	0.0	0.2	3.5	9535	127	17.0	4.5	10.8	11.0	5.0	8.0	
24	2.4	0.0	0.0	2.4	9597	62	15.0	5.0	10.0	12.0	3.0	7.5	
25	2.8	0.0	0.0	2.8	9655	58	20.0	5.0	12.5	17.5	7.0	12.3	
26	1.0	0.0	1.0	2.0	9758	103	16.0	4.0	10.0	16.0	2.0	9.0	
27	2.6	0.0	0.0	2.6	9825	67	15.0	5.0	10.0	10.0	4.0	7.0	
average				2.9		66.0	23.3	11.6	17.5	20.8	11.1	15.9	

Table F5 **June 1990 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water		Rain	Net loss	Accum	Daily	Water Temperature			Air Temperature			
	Add (mm)	Remove (mm)	guage (mm)	from Pan (mm)	Wind (km)	Wind (km)	Max (C)	Min (C)	Avg (C)	Max (C)	Min (C)	Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
31	7.8	0.0	0.0	7.8	5976		23.0	9.0	16.0	17.5	10.0	13.8	
1	5.8	0.0	0.0	5.8	6100	124	23.5	11.5	17.5	22.0	12.0	17.0	
2	8.3	0.0	0.0	8.3	6201	101	28.5	13.0	20.8	26.0	9.0	17.5	
3	2.4	0.0	1.2	3.6	6278	77	27.5	14.5	21.0	27.0	18.0	22.5	
4	0.0	8.5	13.7	5.2	6396	118	26.0	8.0	17.0	25.0	12.0	18.5	
5	3.2	0.0	0.1	3.3	6480	84	17.0	7.5	12.3	13.5	6.0	9.8	
6	0.8	0.0	0.0	0.8	6530	50	17.0	10.0	13.5	17.5	7.5	12.5	
7	0.0	0.0	0.4	0.4	6654	124	24.0	12.0	18.0	22.0	9.0	15.5	
8	3.2	0.0	0.0	3.2	6723	69	25.0	9.5	17.3	22.5	8.0	15.3	
9	0.0	0.0	4.6	4.6	6852	129	27.0	14.5	20.8	19.5	15.0	17.3	
10	0.0	11.6	13.4	1.8	6957	105	18.0	9.0	13.5	17.0	12.0	14.5	
11	6.0	0.0	13.4	19.4	6985	28	26.0	12.5	19.3	23.0	7.0	15.0	
12	5.8	0.0	0.2	6.0	7032	47	27.0	12.5	19.8	25.0	12.0	18.5	
13	7.8	0.0	0.0	7.8	7089	57	31.5	15.0	23.3	26.5	15.0	20.8	
14	1.8	0.0	0.0	1.8	7140	51	24.0	17.0	20.5	24.0	18.0	21.0	
15	4.0	0.0	0.0	4.0	7211	71	30.0	14.5	22.3	26.5	18.0	22.3	
16	5.2	0.0	0.0	5.2	7257	46	29.0	15.0	22.0	28.0	17.5	22.8	
17	0.0	2.4	9.6	7.2	7321	64	31.0	17.0	24.0	27.0	18.0	22.5	
18	0.0	3.3	6.2	2.9	7370	49	31.5	23.0	27.3	27.0	22.0	24.5	
19	0.0	2.2	8.0	5.8	7452	82	29.0	19.2	24.1	26.0	18.5	22.3	
20	3.4	0.0	0.6	4.0	7553	101	23.0	12.0	17.5	26.0	13.5	19.8	
21	14.4	0.0	0.0	14.4	7622	69	21.0	13.0	17.0	19.0	13.0	16.0	
22	0.0	5.3	6.0	0.7	7659	37	19.5	16.0	17.8	18.0	15.0	16.5	
23	0.0	19.2	26.4	7.2	7798	139	27.5	18.0	22.8	21.0	16.0	18.5	
24	1.8	0.0	2.6	4.4	7890	92	27.0	16.0	21.5	24.0	15.0	19.5	
25	2.4	0.0	0.6	3.0	7954	64	27.0	15.5	21.3	21.0	15.0	18.0	
26	7.2	0.0	0.4	7.6	8096	142	30.5	17.0	23.8	24.0	18.0	21.0	
27	3.2	0.0	0.5	3.7	8150	54	25.0	14.5	19.8	26.6	12.5	19.5	
28	5.2	0.0	0.0	5.2	8173	23	28.0	14.5	21.3	22.0	11.0	16.5	
29	0.0	2.4	4.4	2.0	8259	86	18.5	13.5	16.0	20.0	13.0	16.5	
30	0.0	24.0	27.8	3.8	8310	63	29.5	16.5	23.0	18.0	15.0	16.5	
average				5.1		78.2	25.6	14.1	19.8	22.8	13.7	18.3	

Table F6 **July 1990 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water Add (mm)	Water Remove (mm)	Rain guage (mm)	Net loss from Pan (mm)	Accum Wind (km)	Daily Wind (km)	Water Temperature Max (C)	Water Temperature Min (C)	Water Temperature Avg (C)	Air Temperature Max (C)	Air Temperature Min (C)	Air Temperature Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
					8310								
1	3.4	0.0	1.0	4.4	8362	52	26.0	13.5	19.8	23.0	12.0	17.5	
2	6.0	0.0	0.0	6.0	8406	44	32.5	17.0	24.8	26.0	17.0	21.5	
3	1.2	0.0	3.4	4.6	8489	83	29.5	18.0	23.8	26.5	18.0	22.3	
4	1.3	0.0	1.6	2.9	8547	58	25.5	19.0	22.3	25.0	17.0	21.0	
5	7.9	0.0	0.0	7.9	8624	77	28.5	12.5	20.5	22.0	8.0	15.0	
6	4.2	0.0	0.0	4.2	8667	43	26.0	13.0	19.5	21.5	8.0	14.8	
7	6.2	0.0	0.0	6.2	8711	44	30.0	17.0	23.5	24.0	16.0	20.0	
8	0.0	2.5	7.8	5.4	8792	81	30.0	20.0	25.0	26.0	19.0	22.5	
9	5.6	0.0	0.0	5.6	8862	70	30.5	18.5	24.5	26.0	18.0	22.0	
10	7.2	0.0	0.0	7.2	8942	80	29.0	14.5	21.8	24.0	15.0	19.5	
11	5.7	0.0	0.0	5.7	8978	36	30.0	14.5	22.3	24.0	11.0	17.5	
12	4.8	0.0	0.0	4.8	9024	46	25.0	14.0	19.5	22.5	11.0	16.8	
13	4.8	0.0	0.0	4.8	9058	34	31.0	15.5	23.3	25.0	11.0	18.0	
14	4.8	0.0	1.2	6.0	9119	61	32.0	17.0	24.5	26.5	11.0	18.8	
15	1.4	0.0	0.6	2.0	9186	67	29.5	21.5	25.5	27.0	22.0	24.5	
16	7.2	0.0	0.0	7.2	9270	84	31.0	18.5	24.8	26.0	19.0	22.5	
17	0.0	0.0	5.2	5.2	9342	72	30.5	19.5	25.0	27.0	22.0	24.5	
18	8.5	0.0	0.0	8.5	9448	106	33.0	20.5	26.8	30.0	22.0	26.0	
19	10.0	0.0	17.6	27.6	9511	63	30.0	19.0	24.5	26.5	17.0	21.8	
20	0.0	27.8	29.0	1.2	9537	26	22.0	18.0	20.0	26.0	18.0	22.0	
21	2.1	0.0	4.0	6.1	9583	46	33.0	19.0	26.0	26.0	17.0	21.5	
22	0.0	26.4	30.8	4.4	9647	64	31.0	19.0	25.0	26.0	18.0	22.0	
23	0.0	0.2	2.0	1.8	9730	83	20.0	18.0	19.0	20.0	17.0	18.5	
24	4.8	0.0	0.2	5.0	9765	35	32.5	19.5	26.0	26.0	17.0	21.5	
25	3.9	0.0	0.0	3.9	9797	32	34.0	19.5	26.8	26.0	18.0	22.0	
26	5.8	0.0	0.0	5.8	9827	30	35.0	20.0	27.5	30.0	17.0	23.5	
27	4.8	0.0	0.2	5.0	9872	45	35.0	21.0	28.0	31.0	18.0	24.5	
28	5.6	0.0	0.2	5.8	9903	31	35.5	21.0	28.3	30.0	18.0	24.0	
29	5.5	0.0	0.0	5.5	9940	37	36.0	21.0	28.5	31.0	21.0	26.0	
30	6.3	0.0	0.5	6.8	3	63	35.5	21.5	28.5	31.0	20.0	25.5	
31	0.0	4.8	6.8	2.0	47	44	22.0	15.0	18.5	22.0	14.0	18.0	
average				5.8		56.0	30.0	17.9	24.0	25.9	16.4	21.1	

Table F7 **August 1990 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water		Rain	Net loss	Accum	Daily	Water Temperature			Air Temperature			
	Add (mm)	Remove (mm)	guage (mm)	from Pan (mm)	Wind (km)	Wind (km)	Max (C)	Min (C)	Avg (C)	Max (C)	Min (C)	Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
31	0.0	4.8	6.8	2.0	47	44	22.0	15.0	18.5	22.0	14.0	18.0	
1	5.9	0.0	0.2	6.1	110	63	30.0	17.0	23.5	26.0	16.0	21.0	
2	5.5	0.0	0.0	5.5	168	58	32.0	17.0	24.5	26.0	19.0	22.5	
3	5.2	0.0	0.0	5.2	230	62	35.0	13.0	24.0	29.0	19.0	24.0	
4	4.8	0.0	1.9	6.7	284	54	33.0	20.0	26.5	31.0	21.0	26.0	
5	0.0	2.4	5.4	3.0	388	104	27.0	19.0	23.0	25.0	18.0	21.5	
6	0.0	15.6	21.4	5.8	437	49	22.0	18.5	20.3	21.0	18.0	19.5	
7	0.0	0.4	1.6	1.2	456	19	21.0	16.5	18.8	20.0	16.0	18.0	
8	5.6	0.0	0.0	5.6	505	49	31.0	16.0	23.5	25.0	15.0	20.0	
9	4.6	0.0	0.0	4.6	545	40	29.5	18.0	23.8	26.5	19.0	22.8	
10	4.6	0.0	0.2	4.8	626	81	31.5	19.5	25.5	25.0	21.0	23.0	
11	4.0	0.0	0.0	4.0	675	49	32.0	19.5	25.8	27.0	17.0	22.0	
12	2.0	0.0	2.2	4.2	706	31	31.0	19.0	25.0	26.0	15.0	20.5	
13	0.0	24.2	24.8	0.6	778	72	18.0	14.5	16.3	17.0	15.0	16.0	
14	4.8	0.0	0.2	5.0	822	44	29.5	16.0	22.8	23.5	16.0	19.8	
15	4.8	0.0	6.8	11.6	860	38	24.0	17.5	20.8	23.0	17.0	20.0	
16	4.8	0.0	0.0	4.8	897	37	32.0	18.5	25.3	27.0	147.0	87.0	
17	6.0	0.0	0.0	6.0	1001	104	29.5	12.0	20.8	29.0	10.0	19.5	
18	0.0	15.6	21.0	5.4	1085	84	32.0	13.0	22.5	26.0	10.0	18.0	
19	4.6	0.0	0.5	5.1	1154	69	32.5	11.5	22.0	20.0	11.0	15.5	
20	4.2	0.0	0.2	4.4	1212	58	28.0	13.0	20.5	22.0	10.0	16.0	
21	4.8	0.0	0.2	5.0	1258	46	28.5	14.5	21.5	24.0	11.0	17.5	
22	3.4	0.0	0.0	3.4	1296	38	30.0	17.0	23.5	26.5	14.0	20.3	
23	4.8	0.0	0.0	4.8	1336	40	31.0	17.5	24.3	26.0	15.0	20.5	
24	4.8	0.0	0.0	4.8	1389	53	34.0	19.0	26.5	28.0	20.0	24.0	
25	4.8	0.0	0.2	5.0	1434	45	33.0	22.0	27.5	29.0	20.0	24.5	
26	3.5	0.0	0.0	3.5	1465	31	34.0	21.0	27.5	30.5	21.0	25.8	
27	0.0	2.6	6.0	3.4	1513	48	29.5	19.5	24.5	26.0	22.0	24.0	
28	4.2	0.0	1.8	6.0	1583	70	33.0	20.5	26.8	26.0	18.0	22.0	
29	4.8	0.0	0.0	4.8	1628	45	32.5	14.5	23.5	25.0	15.0	20.0	
30	4.2	0.0	0.0	4.2	1660	32	27.5	16.0	21.8	23.0	18.5	20.8	
31	5.0	0.0	0.0	5.0	1703	43	29.8	17.0	23.4	26.0	13.5	19.8	
average				4.8		53.4	29.8	17.0	23.4	25.3	20.6	23.0	

Table F8 **September 1990 Evaporation Pan Monthly Record. Brace Research Instute, Macdonald College, Ste. Anne de Bellevue, Quebec.**

	Water		Rain	Net loss	Accum	Daily	Water Temperature			Air Temperature			
	Add (mm)	Remove (mm)	guage (mm)	from Pan (mm)	Wind (km)	Wind (km)	Max (C)	Min (C)	Avg (C)	Max (C)	Min (C)	Avg (C)	Remarks
Date	1	2	3	4	5	6	7	8	9	10	11	12	
					1703								
1	4.2	0.0	0.0	4.2	1768	65	28.5	18.5	23.5	26.0	18.5	22.3	
2	4.8	0.0	0.0	4.8	1865	97	28.0	12.0	20.0	24.0	10.0	17.0	
3	4.0	0.0	0.0	4.0	1922	57	26.5	13.5	20.0	22.0	8.5	15.3	
4	0.0	1.7	5.8	4.1	1969	47	28.0	13.0	20.5	25.0	15.0	20.0	
5	1.4	0.0	0.4	1.8	1993	24	23.0	15.0	19.0	25.0	12.0	18.5	
6	0.0	7.2	10.0	2.8	2025	32	26.5	17.0	21.8	23.0	18.0	20.5	
7	1.0	0.0	1.6	2.6	2103	78	19.5	6.5	13.0	20.0	4.0	12.0	
8	2.6	0.0	0.0	2.6	2155	81	22.0	7.0	14.5	21.0	5.0	13.0	
9	2.0	0.0	0.0	2.0	2197	42	19.5	12.0	15.8	19.0	8.0	13.5	
10	0.0	0.2	1.0	0.8	2247	50	20.5	12.0	16.3	18.0	13.0	15.5	
11	4.4	0.0	0.0	4.4	2303	56	26.0	11.0	18.5	20.0	7.0	13.5	
12	3.0	0.0	0.0	3.0	2338	35	25.0	12.5	18.8	25.0	12.0	18.5	
13	3.2	0.0	0.0	3.2	2413	75	22.0	14.5	18.3	22.0	12.0	17.0	
14	0.6	0.0	4.4	5.0	2542	129	25.0	15.0	20.0	27.0	16.0	21.5	
15	0.5	0.0	2.2	2.7	2692	150	18.5	7.0	12.8	18.5	8.0	13.3	
16	3.6	0.0	0.0	3.6	2727	35	25.5	6.5	16.0	21.0	10.0	15.5	
17	2.8	0.0	0.0	2.8	2806	79	14.5	5.5	10.0	11.0	5.0	8.0	
18	2.4	0.0	0.0	2.4	2842	36	18.0	6.0	12.0	16.0	2.0	9.0	
19	6.8	2.7	0.0	4.1	2898	56	15.5	10.5	13.0	15.0	10.0	12.5	
20	2.4	0.0	0.0	2.4	2954	56	18.0	11.0	14.5	16.0	10.0	13.0	
21	0.0	2.6	4.2	1.6	3021	67	18.0	11.0	14.5	16.5	11.0	13.8	
22	0.0	1.0	4.1	3.1	3103	82	18.5	10.0	14.3	15.0	9.5	12.3	
23	0.0	0.8	1.3	0.5	3155	52	18.5	8.5	13.5	16.0	5.0	10.5	
24	0.7	0.0	0.4	1.1	3237	82	13.5	9.0	11.3	13.0	7.0	10.0	
25	1.8	0.0	0.0	1.8	3298	61	20.0	11.0	15.5	20.0	11.5	15.8	
26	1.1	0.0	0.3	1.4	3322	24	20.0	11.0	15.5	12.0	6.0	9.0	
27	1.6	0.0	0.0	1.6	3357	35	22.5	12.5	17.5	20.0	10.0	15.0	
28	0.0	0.4	4.0	3.6	3398	41	22.5	12.5	17.5	19.5	10.5	15.0	
29	0.0	15.4	19.0	3.6	3457	59	14.0	9.5	11.8	22.5	12.0	17.3	
30	0.0	14.4	18.4	4.0	3584	127	13.5	7.0	10.3	14.0	9.5	11.8	
average				2.9		63.7	21.0	10.9	16.0	19.4	9.9	14.7	

Appendix G

Basic Programs For Creating Drainmod Input files

This is a program to arrange RAINFALL data from a file to suit the input format for DRAINMOD 4.0

```
OPEN "d:90.prn" FOR INPUT AS #1
OPEN "d:90rain.out" FOR OUTPUT AS #2
DIM yr(500), moncnt%(500), day(500), max(500), min(500), rain(500)
DIM yr%(500), mon%(500), day%(500), max%(500), min%(500), rain%(500)
CLS
i = 0
cnt = 0
k = 0
maxj = 7
DO UNTIL EOF(1)
   i = i + 1
   INPUT #1, mon%(i), day%(i), rain(i), max(i), min(i)
LOOP
cnt = i
moncnt%(6) = 30: moncnt%(7) = 31: moncnt%(8) = 31: moncnt%(9) = 30:
FOR i = 1 TO cnt
   rain%(i) = INT(rain(i) * 25.4)
   max%(i) = INT(max(i) * 9 / 5 + 32)
   min%(i) = INT(min(i) * 9 / 5 + 32)
NEXT i
year = 1990
id = 514000
hour = 4
'========================== P R I N T  R O U T I N E ============
mk = 0
WHILE k < cnt
      PRINT USING "########"; id;
      PRINT USING "#####"; year;
      PRINT USING "##"; mon%(k + 1);
      FOR j = 1 TO maxj
         k = k + 1
          PRINT USING "###"; day%(k);
          PRINT USING "##"; hour;
          PRINT USING "####"; rain%(k);
          mk = mk + 1
          IF mk = moncnt%(mon%(k)) THEN
                 mk = 0
                 j = maxj
                 END IF
          NEXT j
      PRINT
WEND

k = 0: mk = 0:j = 0
WHILE k < cnt
      PRINT #2, USING "########"; id;
      PRINT #2, USING "#####"; year;
      PRINT #2, USING "##"; mon%(k + 1);
      FOR j = 1 TO 12
         k = k + 1
          PRINT #2, USING "###"; day%(k);
          PRINT #2, USING "##"; hour;
          PRINT #2, USING "####"; rain%(k);
          mk = mk + 1
        IF mk = moncnt%(mon%(k)) THEN mk = 0: j = 12
      NEXT j
 PRINT #2,
WEND
```

This is a program to arrange TEMPERATURE data from a file to suit the input format for DRAINMOD 4.0

```
OPEN "d:90.prn" FOR INPUT AS #1
OPEN "d:90temp.out" FOR OUTPUT AS #2
DIM yr(500), mon(500), day(500), max(500), min(500), rain(500),yr%(500)
DIM  mon%(500), moncnt%(12), day%(500), max%(500), min%(500), rain%(500)
CLS
i = 0: cnt = 0: k = 0:
DO UNTIL EOF(1)
   i = i + 1
   INPUT #1, mon%(i), day%(i), rain(i), max(i), min(i)
LOOP
cnt = i
FOR i = 1 TO cnt
   rain%(i) = INT(rain(i) * 25.4): max%(i) = INT(max(i) * 9 / 5 + 32)
   min%(i) = INT(min(i) * 9 / 5 + 32)
NEXT i
year = 1990: id = 514000: hour = 7
'========================== P R I N T  R O U T I N E =============
FOR n = 1 TO 4
 mon%(n) = n + 5
NEXT n
moncnt%(6) = 30: moncnt%(7) = 31: moncnt%(8) = 31: moncnt%(9) = 30
WHILE k < cnt
  FOR i = 1 TO 4
     PRINT USING "######"; id;: PRINT USING "#####"; year;
     PRINT USING "##"; mon%(i);
        FOR j = 1 TO 31
         k = k + 1
         PRINT USING "###"; max%(k);: PRINT USING "###"; min%(k);
         mk = mk + 1
         IF mk = moncnt%(mon%(k)) THEN mk = 0: j = 31
     NEXT j
     PRINT
 NEXT i
WEND
 k = 0: mk = 0
WHILE k < cnt
  FOR i = 1 TO 4
     PRINT #2, USING "######"; id;: PRINT #2, USING "#####"; year;
     PRINT #2, USING "##"; mon%(i);
  FOR m = 1 TO 2
       IF m = 1 THEN
         length = 14
       ELSE length = 17
       END IF
     FOR j = 1 TO length
         k = k + 1
         IF m = 1 AND j = 1 THEN
            PRINT #2, USING "########"; max%(k);
          ELSE
            PRINT #2, USING "###"; max%(k);
          END IF
         PRINT #2, USING "###"; min%(k);
         mk = mk + 1
         IF mk = moncnt%(mon%(k)) THEN mk = 0: j = 31
     NEXT j
     PRINT #2,
    NEXT m
 NEXT i
WEND
CLOSE
```

This is an example of an input file for both the RAINFALL and for the TEMPERATURE programs.

month	**day**	**rain** mm	**temperature** max	min
6.0	21.0	0.0	27.0	19.0
6.0	22.0	0.0	31.0	20.0
6.0	23.0	0.0	33.0	22.0
6.0	24.0	0.0	27.0	16.0
6.0	25.0	0.0	26.0	19.0
6.0	26.0	0.0	26.5	18.5
6.0	27.0	0.1	30.0	20.0
6.0	28.0	4.5	23.5	13.0
6.0	29.0	0.0	23.0	13.0
6.0	30.0	0.0	26.0	15.0
7.0	1.0	1.6	21.5	15.0
7.0	2.0	0.0	31.0	16.0
7.0	3.0	0.0	30.0	19.0
7.0	4.0	0.0	30.0	24.0
7.0	5.0	0.0	31.5	18.0
7.0	6.0	3.2	31.0	21.0
7.0	7.0	0.0	27.0	13.0
7.0	8.0	0.0	26.0	15.0
7.0	9.0	16.6	26.5	17.0
7.0	10.0	12.8	26.5	16.0
7.0	11.0	2.1	25.0	16.0
7.0	12.0	0.0	26.5	16.0
7.0	13.0	2.3	26.0	15.0
7.0	14.0	0.0	25.0	11.0
7.0	15.0	0.0	25.0	13.0
7.0	16.0	0.0	27.0	11.5
7.0	17.0	0.0	26.5	15.0
7.0	18.0	0.0	27.0	16.0
7.0	19.0	0.0	26.5	13.5
7.0	20.0	0.0	26.5	12.0
7.0	21.0	0.0	26.0	15.0
7.0	22.0	0.0	31.0	18.0
7.0	23.0	0.0	31.5	20.5
7.0	24.0	0.0	33.0	22.5
7.0	25.0	0.0	33.0	21.0
7.0	26.0	0.0	35.0	23.0
7.0	27.0	7.2	26.5	19.0
7.0	28.0	0.0	24.0	12.5
7.0	29.0	0.0	24.0	13.0
7.0	30.0	0.0	26.0	14.0
7.0	31.0	0.0	26.0	12.0
8.0	1.0	0.0	29.5	20.5
8.0	2.0	3.8	25.0	19.0
8.0	3.0	13.1	30.0	19.0
8.0	4.0	32.0	27.0	22.0
8.0	5.0	0.0	30.0	21.5
8.0	6.0	1.8	31.0	15.0

These are sample output files created by the programs.

The daily maximum and minimum temperature file.

```
514000 1990 6       77 66 80 66 87 68 91 71 80 60 78 66 79 65 86 68 74 55 73 55 78 59
 70 59 87 60 86 66 86 75 88 64 87 69 80 55 78 59 79 62 79 60 77 60 79 60 78 59 77 51 77 55 80
52 79 59
514000 1990 7       80 60 79 56 79 53 78 59 87 64 88 68 91 72 91 69 95 73 79 66 75 54 75 55 78
57 78 53
 85 68 77 66 86 66 80 71 86 70 87 59 66 51 66 51 75 57 78 57 78 64 73 66 78 66 78 60 79 68 75
55 73 50
514000 1990 8       78 50 80 62 73 64 78 59 73 62 75 53 66 37 66 48 68 50 73 52 78 59 77 68 75
54 71 59
 73 57 69 44 68 42 73 50 71 57 80 57 78 59 78 69 79 68 79 60 68 53 75 57 69 53 61 54 68 46 66
54 60 51
514000 1990 9       72 51 68 51 73 59 77 53 78 51 51 41 53 37 63 44 60 35 50 39
```

The daily rainfall file.

```
514000 1989 6 20 4   15 21 4   0 22 4   0 23 4   0 24 4   0 25 4   0 26 4   0 27 4   2 28 4 114
29 4   0 30 4   0
514000 1989 7  1 4   40  2 4   0  3 4   0  4 4   0  5 4   0  6 4  81  7 4   0  8 4   0  9 4 421
10 4 325 11 4  53 12 4   0
514000 1989 7 13 4   58 14 4   0 15 4   0 16 4   0 17 4   0 18 4   0 19 4   0 20 4   0 21 4   0
22 4   0 23 4   0 24 4   0
514000 1989 7 25 4    0 26 4   0 27 4 182 28 4   0 29 4   0 30 4   0 31 4   0
514000 1989 8  1 4    0  2 4  96  3 4 332  4 4 812  5 4   0  6 4  45  7 4   0  8 4   0  9 4   0
10 4   0 11 4  15
```