Effects of duration of water stress at different growth stages on growth and yield of Soybeans (*Glycine max* (L.) Merrill)

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Table of Contents

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List of Figures | Page

List of Tables

Page

List of Plates

List of Appendices

Abstract

Four soybean cultivars (*viz.* Evans, Geiso, Maple Arrow and S.J.4) were subjected to water stress at three different reproductive growth stages: i) entire reproductive growth stages (R1 to R7) ii) early reproductive growth stages (R1 to R4) and iii) late reproductive growth (R4 to R7). The experiment was conducted in the climate laboratory at the Plant Physiology Division D.S.I.R. Palmerston North, New Zealand, with $31^{0}/23^{0}$c (day/night temperature) 70/90% RH (day/night relative humidity) and 14 hours photoperiod.

The growth and development of the soybeans were markedly affected by water stress. Leaf area, final plant length, number of nodes and total plant dry weight from the stress treatments were reduced.

Seed yield per plant from the three stress treatments were only 10.7, 49.6, and 24.1% relative to that of control treatment. The response of soybean yield depended on both the timing and the duration of stress in relation to growth stages whilst some other plant characters such as plant length and the number of nodes responded more to the timing rather than the duration of stress. Cultivars with the determinate growth type (*viz.* Evans and Maple Arrow) were apparently more sensitive to stress at the early phase of reproductive growth (R1 to R4) whilst the indeterminate growth type (*viz.* Geiso and S.J.4) were more sensitive to water stress at the later phase of reproductive growth (R4 to R7). The number of pods per plant was the most important yield component in determining yield although in Evans and the early stress treatment the average seed weight was the most important component.

The rank of cultivars, from low to high sensitivity to water stress is Maple Arrow, Evans, Geiso and S.J.4. S.J.4 also reacted differently from

the other three cultivars in many aspects.

The drought tolerance test estimated through a measurment of electrolyte leakage from the cells was used and discussed.

Two methods of genotype x environment interaction analysis (regression analysis and discriminant analysis) were used. The discriminant analysis had some advantages in the study of GE interaction e.g. it could be done with several characters at once and compared with the regression method it could be used with a much lesser number of cultivars and environments.

Key words: Soybeans, water stress, growth stages, yield and yield components, drought tolerance test, GE interaction, discriminant analysis, principal component analysis.

CHAPTER I

INTRODUCTION

Soybean (*Glycine max* (L) Merrill) is one of the major cultivated legume crops in Thailand. It is used for many purposes with human consumption ranked first amongst them. Due to a greater demand, the area and production of soybean has increased more than 100% from 1970 to 1975 (Shanmugasundaram, 1979). However low yield tended to discourage expansion of farm acreage. Average yield in Thailand, 1.2 ton/hectare is only about 60% of average soybean yield in United States. The major reasons for the prevailing low soybean yield in Thailand are the lack of strong, sustained varietal development programs, nonavailability of adapted high yielding varieties, disease and insect problems (Shamugasundarum ,1979) and the lack of water.

Thailand's climate is divided into two distinct seasons: a dry and a wet season. The monsoon rains start in May and continue until October or November. The rainfall has a bimodal distribution, so water stress can occur frequently, the most common causes of water stress are due to erratic start and/or early cessation of the rain during the growing season.

Several workers have reported the adverse effects of water stress in soybean at different stages of growth (Shaw and Laing, 1966; Doss *et al*., 1974; Momen *et al*., 1979; Wien *et al* ., 1979). Some other workers have also found significant cultivar x water stress interaction, suggesting differences amongst the cultivars for water response (Mederski *et al*., 1973; Sammons *et al*., 1981). The need to define and understand the effects of water stress, especially that applied during different growth stages, on the growth and yield of soybean, and the responses of different cultivars to such stress, may make it possible to develop or select suitable cultivars that can be adapted in Thailand.

Four soybean cultivars (*viz* Evans, Geiso, Maple Arrow and S.J.4), including one recommended cultivar from Thailand (S.J.4) were studied in this experiment.

The objectives of this experiment were:

1. To determine the effects of different durations of water deficit applied at different growth stages on the growth and yield of 4 soybean cultivars.
2. To compare the adaptability of the 4 soybean cultivars subjected to different water stress treatments.

CHAPTER II

REVIEW OF LITERATURE

2.1 Introduction

One of the most widely limiting factors for crop production on a global basis is water (Hsiao *et al.*, 1976).

The relationship between plant growth and water deficit has been reviewed by many authors, amongst others were Vaadia *et al.* (1961), Shaw and Laing (1966), Salter and Goode (1967), Hsiao (1973), Hsiao *et al.* (1976), Begg and Turner (1976), Turner and Begg (1981).

Apart from a brief review of (i) development of plant water deficit and (ii) plant response to water deficit, the emphasis of this review will be focused on the points directly relevant to the objectives of this thesis. These are:

a. growth and development of soybean

b. effects of water deficit on vegetative growth of soybean

c. effects of water deficit on reproductive growth of soybean

In addition, a brief review on the technique of the drought tolerance test and methods of genotype x environment interaction analysis will be presented.

2.1.1 Terminology

The following definitions have been adopted in this thesis.

Water deficit: refers to the lowering of plant water potential from that equal to pure free water at the same location in space and at the same temperature.

Water stress: in the broad sense this term can apply to both deficit or excess water. However, in this thesis this term will be refered to stress produced by water deficit only.

2.2 Development of plant water deficit

Water moves only from sites of high potential to those of low potential, thus for a plant to extract water from the soil, the potential energy of the water in the plant must be lower than that of water in the soil. This potential difference or water potential gradient between the evaporating tissues of the plant and the soil water in the root zone depends on the evaporative demand, the extent to which the plants can meet the demand, and the water conducting properties of the soil and the plant.

As the stomata open and the evaporative demand increases, water evaporates from mesophyll cells of the leaves. The lowered water potential in the transpiration pathway provides the driving force for the movement of water out of adjacent tissues. As a result of this loss, water deficit develops in the leaf, stem and root tissues. (Turner and Begg, 1981). Thus for a plant going into stress, transpiration will exceed water uptake by the roots as water is drawn out of tissues surrounding the xylem, and a steady state is reached in which transpiration equals water uptake. During recovery from stress as the water deficit in these tissues is being replenished, transpiration will be less than water uptake. In general all plants undergoing active transpiration are experiencing some degree of water deficit (Begg and Turner, 1976).

Water deficits can be caused either by excessive loss of water or by inadequate absorption, or a combination of the two. Deficits caused by excessive loss of water are more common in crop plants than those caused by reduced absorption, although the latter usually are more severe and more prolonged (Kramer, 1963).

2.3 Plant response to water deficit

The development of water deficit leads to a wide range of responses by the plant. It has often been stated that cell division appears less sensitive to water deficit than does cell enlargement (Vaadia *et al*., 1961; Slatyer, 1969). The sensitivity of cell enlargement to water deficit can be demonstrated by the work on corn, soybean and sunflower by Boyer (1970a) in a controlled environment. He found that rapid leaf enlargement was uniformly sensitive to low leaf water potentials in the three species studied, the major changes occured within a 0.2 to 0.3 MPa interval, with maximal rates of enlargement at about -0.15 to -0.25 MPa and with strongly inhibited rates at -.4 to-.5 MPa. One of the most important consequences of the sensitivity of cell enlargement to small water deficit is a marked reduction in leaf area which may reduce crop growth rate particularly during the early stages of growth. One of the most damaging features of a reduction in leaf area is the fact that the effect is permanent and in the case of a determinate crop there is no scope for compensation via an increase in the number of leaves (Begg and Turner, 1976). Water deficit can also affect leaf area through its effect in hastening the rate of leaf senescence (Slatyer, 1973).

According to a comprehensive review by Hsiao (1973), as water potential decreases further from that affecting cell growth, stomata may begin to close. It is now generally recognised that stomata do not respond to a change in leaf water potential or relative water content until a critical threshhold level is reached i.e. -1.0 to-1.2 MPa for soybean in a controlled environment (Boyer, 1970b) .

In considering yield in relation to water stress, the simplest parameter to be measured is total biomass. However, the situation will be complicated when the yield considered is only a part of the total biomass (Hsiao, 1973) because the proportion of the total biomass actually ends up as yield will be determined by the partition of assimilates into the different plant parts (Hsiao *et al*., 1976). The components of grain yield that are influenced by water stress depend largely on the timing of stress in relation to the development of the portion of the plant utilized for grain yield. So, the yield will usually depend more on the developmental stages (Hsiao, 1973). For example in cereal the sensitive growth stages to water deficit are during the formation of the reproductive organs and during flowering (Salter and Goode, 1967), whereas the pod development period seems to be the most sensitive period in soybeans (Doss *et al.*, 1974).

2.3.1 Recovery from water deficit

A frequently observed effect during recovery from stress is a more rapid rate of growth and development in the previous stressed plant than that of the unstressed control (Begg and Turner, 1976).

The higher growth level than control ("compensatory growth") after a mild water stress of short duration had been shown in tomatoes by Gates (1955) and tobacco by Hopkinson (1968). However, Hsiao and Acevedo (1974) warned that claims for compensatory growth often do not take into account the earlier maturation and senescence of non-stressed control tissue. The importance of the interactive effect with stage of plant development in interpreting results has been clearly indicated by Ludlow and Ng (1974) in their work with *Panicum maximum* where water deficits delayed ontogeny in terms of apparent photosynthesis, stem elongation and flowering.

Leaf enlargement was earlier shown to be very sensitive to stress (Section 2.3), in the previously stressed plants relief of stress resulted in greater rate of leaf extension, i.e. in prairie grass.Chu *et al.* (1979) found that rate of leaf extension for individual stressed leaves during recovery was up to 20% higher than those leaves of the same insertion on well water-controlled plants, they explained that rapid cell expansion could occur following rewatering, giving rise to the observed high rates. With severe stress, in sunflower at leaf water potentials below -0.4 MPa enlargement was completely suppressed and recovery of a normal rate of leaf enlargement did not occur upon rewatering (Boyer, 1970a).

2.4 Growth and development of soybean

2.4.1 Vegetative growth

The development of above ground part of soybean begins with the emergence of hypocotyl from the soil. Under favourable conditions for growth the plant emerges 4-7 days after sowing. The lowermost node is the point of attachment for the cotyledons, the next node gives rise to the opposite unifoliolate leaves and all subsequent nodes produce single trifoliolate leaves alternately up the stem (Hicks, 1978). Most of the branching is the first order branching on the main stem. Both genetic and environmental effects such as daylength, and spacing will affect branching (Carlson, 1973). Depending upon planting density, 0-6 branches per plant are usual, all nodes, however, possess the potential for both branching and floral development (Shibles *et al.*, 1975).

Soybean varieties are described as having either a determinate or an indeterminate growth habit. Determinate types usually complete their vegetative growth prior to flowering and the main stem ends in a rather large terminal raceme. Indeterminate growth types continue to increase in height for several weeks after beginning to flower (Hartwig, 1973).

The number of nodes and internodes that ultimately make up the main stem depends on the reaction of the genotype to the photoperiod in which it is grown, and whether the growth type is determinate or indeterminate. When determinate genotypes that are adapted to long days are grown in short photoperiods, plants may form as few as six nodes and stem lengths may be as short as 15 cm. When indeterminate genotypes that are adapted to short days are grown in long photoperiods the plants tend to be viny and stems may be as long as four meters (Hinson and Hartwig, 1977).

2.4.2 Reproductive growth

Soybean cultivars differ in critical day-length required for flower initiation. Temperature also influences the time required to reach floral differentiation. The node producing the first flower usually is the second trifoliolate leaf node or above. Flowers develop progressively along the main stem from the first flowering node and outward toward tips of lateral branches (Hicks, 1978). Soybean is self-pollinated, pollination occurring when the flower opens or slightly previously. Pods develop slowly for the first few days following fertilization. Rapid elongation begins about the fifth day, and full length is attained by the fifteenth to twentieth day. (Shibles *et al.*, 1975).

Mature pods may contain one to five seeds of which two to three seeds per pod are most common. Depending on cultivars, pod length varies from 2 to 7 cm. (Hicks, 1978). Final seed size is influenced both environmentally and genetically. Year to year and location to location variation in average seed size of cultivar range up to 60%. Average seed weight ranges from 120-280 mg per seed (at 13% moisture). Cultivars which produce fewer seeds tend to have a large seed size (Shibles *et al.*, 1975).

Rate of dry weight increase of different cultivars in the bean fraction was similar. Major differences in seed yield were attributable to length of the bean development period rather than the rate of daily growth (Hanway and Weber, 1971).

2.5 Effect of water stress on growth and yield of soybean

2.5.1 Effects on vegetative growth

Water deficit during the vegetative stages of soybean reduces the rate of plant growth. In controlled environment study, as leaf water potential decreased, leaf enlargement was inhibited earlier and more severely than photosynthesis or respiration, it was markedly reduced when leaf water potential dropped to about -0.4 MPa (Boyer, 1970a). Bunce (1978) found that leaf expansion rates were reduced 1-2 days before net photosynthesis rates per unit leaf area were reduced, but at night leaf expansion still continued after net photosynthesis rates were severely reduced by stress (leaf water potential reached -2.0 or -4.0 MPa).

During early growth, the soybean crop growth rate is a linear function of intercepted irradiance (Shibles and Weber, 1965). So an early drought would be expected to reduce crop growth by limiting leaf area (Mederski *et al.*, 1973). Silvius *et al.* (1977) indicated that the reduction of leaf expansion rates of soybean in a controlled environment which were noted first on day 3 after withholding water and by day 8 the leaf area and dry weight of the control plant at vegetative growth stages were more than double that of water stressed plants. Leaf area also had been reduced by accelerating the rate of senescence of the physiologically older leaves (Volkenburg and Davies, 1977). In rainfed areas, Constable and Hearn (1978) found a 68 and 90% loss of leaf from main stem and branches respectively over an 8 day period, as available water approached wilting point.

Water stress caused a significant decrease in dry weights of leaves, stems, petioles and nodules but an increase in root dry weight of soybeans. In a growth chamber study, dry weight of leaves decreased 20% compared to a 16% increase in the root dry weight in the -1.2 MPa stress treatment (Finn and Brun, 1980). This change in percent plant part dry weight resulted in reduced shoot to root dry weight ratio (Finn and Brun, 1980; Sivius *et al.*, 1977). A difference in plant height between adequately watered plots and those under limited soil water regime was also found (Doss *et al.*, 1974; Momen *et al.* 1979).

2.5.2 Effects on reproductive growth and yield

Various experimental results indicated that most of the economically important leguminous crops have marked moisture-sensitive stages of growth, if seed yield is taken as the criterion of plant response. The general pattern of response indicates that soil moisture conditions before flowering have little influence on pod and seed yields provided that the soil does not get so dry that permanent wilting of the plant occurs, but soil moisture conditions during the reproductive growth period will have a greater effect. (Salter and Goode 1967).

The components of yield that are influenced by water stress depend largely on the timing of stress in relation to the development of the portion of the plant utilized for grain yield (Begg and Turner, 1976). Water stress during flowering increases abortion of flowers and young pods (Whigham and Minor, 1978). Stress of short duration during early flowering usually causes little reduction in the number of pods per plant. Soybeans can compensate for early flower and pod abortion by the increased set of later flowers providing sufficient moisture becomes available (Pendleton and Hartwig, 1973), for example, Shaw and Liang (1966) imposed short term (1 week) moderate water stress (RWC of upper leaves was at or below 85% for 4 days) on plants grown outdoors in large potometers to study the sensitivity of yield to stress at various stages of reproductive development. Their data illustrated that stress during early flowering resulted in less than 10% yield reduction, flower and pod drop occurred in the lower parts of the plant, but compensation in the form of more pod set on upper nodes almost negated the pod loss. During mid-flowering lower nodes resulted in yield loss about 20%. However this was partially compensated for by increased bean set on upper nodes and increased bean size at lower nodes. Compensatory capacity diminished, as stress was imposed later, and the responses shifted from pod number to seed per pod and seed size. However, Momen *et al.*(1979) indicated that seed per pod seemed quite insensitive to moisture stress (leaf water potential -1.0 to -2.0 MPa) imposed at 4 different times during the reproductive period of the soybean. The effects of water stress during the pod filling stage causing the highest reduction in seed yield is quite often indicated. For example, 50% of yield loss in field grown soybeans at 10% available soil water (Doss *et al.*,1974) and about 40% of yield loss in growth chamber grown soybeans when leaf water potential was down to -2.3 MPa (Sionit and Kramer, 1977) had been reported. Sionit and Kramer (1977) indicated that stress at this stage produced the smallest seeds and shortened the length of maturation period. Constable and Hearn (1978) also pointed out that water stress at this period caused early leaf death and cessation of pod filling, thus decreasing yield. However, pod numbers are reduced by stress during flowering and early pod set so yield is very sensitive at this stage (Salter and Goode, 1967; Sionit and Kramer, 1977). Momen *et al.* (1979) found that the greatest seed reduction due to moisture stress (leaf water potential about -1.2 MPa) occurred during this period, unfortunately their data did not show the size of reduction.

2.6 Drought tolerance test

The term "drought resistant" as applied to crop plants is normally used as an all-embracing term to describe those varieties or species which are able to grow and yield satisfactorily in areas liable to periodic drought (May and Milthorpe, 1962). Three main types of drought resistance may be classified:

1. Drought escape (May and Milthorpe 1962, Levitt 1972) or ability to complete the life cycle before being subjected to serious water stress.
2. Drought avoidance (Levitt, 1972) or drought endurance, with high internal water content (May and Milthorpe, 1962) maintained during the period of drought by virtue of a deep root system or by reducing transpiration.
3. Drought tolerance (Levitt, 1972) or drought endurance, with low internal water content (May and Milthorpe, 1962) during drought but with the ability to recover and grow rapidly when soil water is replenished.

In crop plants there is no doubt that the greatest advance in breeding for water-limited environment has been achieved by a shortening of the life cycle, thereby allowing the crop to escape drought (Turner, 1979). However given an adequate water supply, yield is often positively correlated with maturity date in determinate annual crops therefore selection for earliness to avoid severe soil water deficit may mean lower yields in years of adequate water supply (May and Milthorpe, 1962).

To select drought resistant genotypes, physiological screening tests combined with field testing could be applied. The ideal physiological screening test of drought resistance would be:

1. Highly correlated with drought resistance under field conditions (i.e. high grain yields) where stress occurred at the sensitive growth stages.
2. Rapid, accurate and capable of handling large numbers of samples.
3. Applicable at an early stage of plant development.
4. Non destructive. (Hanson and Nelsen, 1980).
5. Have high heritability (if used as a selection criterion).

2.6.1 Method of drought tolerance test.

A recent review by Bewley (1979) reported that the critical role of cell membrane stability under conditions of moisture stress, as a major component of drought, may be estimated through measurement of electrolyte leakage from the cells. Such a method, for the drought tolerance test was developed for sorghum by Sullivan and Ross (1979) and wheat by Blum and Ebercon (1981). The detail of this method is presented in appendix 3.

2.7 Genotype x environment interaction

Plant performance reflects the interplay of genetic and non genetic factors, so that for many plant characters, the relative performance of genotypes may vary in different environments. This is termed genotype x environment interaction (Byth, 1981). The different durations or levels of water stress is an aspect of change in environment hence, genotype x environment interaction can also mean genotype x stress interaction and the technique of genotype x environment interaction analysis can be used. For example, Mederski and Jeffers (1973) found that when eight varieties of soybeans were grown at different soil moisture conditions a significant amount of variety x stress level interaction on seed yield was detected.

Various techniques which have been employed in seeking a solution to genotype x environment interaction have been reported (Hill, 1975).

2.7.1 Methodology review

2.7.1.1 Regression analysis

Amongst others, several workers have considered genotype x environment interactions as linear functions of the environment (i.e. Finlay and Wilkinson, 1963). In this method the mean yield of all varieties (site mean yield) was used as a quantitative measure of the environment upon which the variety yields were regressed. Because the individual variety yields are plotted against the mean of all the variety yields, the population mean has a regression coefficent (β_1) = 1.0. They suggested that β_1 was a useful stability parameter indicating a variety's response to the range of environment tested. Freeman and Perkins (1971) criticized this technique in that it led to statistically invalid regressions in which the sum of squares for the regressions was the same as the total sum of squares between environments, and not part of it. They suggested that it might be better to use this approach to analyse genotype x environment interaction by regression on independent variables rather than to use regression on the environmental mean. Knight (1970) also examined the Finlay and Wilkinson regression technique by applying it where a precisely measured environmental factor was varied. He concluded that when making biological interpretation, recognition should be taken of the following:

1. A genotype that differs from the majority of genotypes under consideration either below or above their optimum will show a marked deviation around its regression line.
2. That different limiting factors (e.g. frost or drought) result in equally low yields. Genotypes are unlikely to be similarly ranked under these factors but this difference in ranking is not readily detected by the existing regression technique.
3. That there may be no yield from some of the genotypes if a threshhold

level is surpassed.

4. That combining in the one analysis data from different lengths of growing period, or different growth phases, can be very misleading.

5. That the interpretation will be greatly affected by scale in the analysis

For the regression coefficient to be a useful parameter to discriminate among genotypes on performance it must be significant for a considerable number of genotypes in the set that is heterogeneous among regressions must account for a substantial portion of the variation due to genotype x environment interaction (Shorter, 1981). From a number of analyses conducted at the University of Queensland, Shorter (1981) found that linearity ranged from 0-96.8% for individual entries but mean linearity generally was less than 16%, indicating that the performance of most genotypes was not a linear function of the environmental index.

2.7.1.2 Multivariate techniques

Multivariate analysis approach seems to be useful as the way to study genotype x environment interactions. The analysis enables for categorization of environmental conditions and for the classification of varieties for yield stability (Sneep and Hendriksen, 1979). The former defies "area" within a region which is similar. The latter identifies genotypes with stable trends over environments. A number of different multivariate analytical techniques have been suggested. Only some of these techniques are presented in this review.

(a) Principal component analysis. In this analysis the phenotypes of a genotype in different environments could be considered to be a separate character of the genotype. In this method, components of variation within genotypes are taken out successively, each component has maximum variance out of all possible normalized linear functions statistically uncorrelated and geometrically orthogonal to the one preceding it. (Cooley and Lohnes 1971). Freeman and Dowker (1973) applied principal component analysis to data recorded from a series of yield trials in carrots after the regression analysis had been only partially successful in explaining the observed genotype x environment interactions. They were able to demonstrate the importance of site x year and density effects upon the yield differences between varietal groups.

(b) Cluster analysis. This analysis has been employed for the analysis of genotype x environment interactions from several viewpoints. Its use is in summarising patterns of genotypic performance and environmental productivity. The application and method of using this analysis has been described (De Lacy, 1981). For this purpose it has proved a powerful tool for substantially reducing the complexity of large data sets characteristic of multi-environmental testing. (Mungomery *et al.*, 1974; Byth *et al.*, 1976).

(c) Discriminant analysis is one kind of approach which may be used (Gordon *pers com*). This analysis aims at distinguishing between two or more groups on the joint basis of several attributes. The mathematical outcome of discriminant analysis is a linear function of the discriminating attributes so that the function variance amongst groups is maximized while the variance within groups is minimized (Cooley and Lohnes 1971).

CHAPTER III

MATERIAL AND METHODS

Four soybean cultivars namely Evans, Geiso, Maple Arrow and S.J.4 were grown in 1 gallon pots in a mixture of Opiki silt loam and sand (70:30 vol/vol). The potting mixture was mixed well and the same amount was put in every pot. Seeds were sown on 12th November 1980. Two climate rooms at the Climate Laboratory, Plant Physiology Division, Department of Scientific and Industrial Research, Palmerston North, New Zealand, were used with the following conditions:

- Temperature 31/23^{o}C (Day/night $\pm$ 0.5^{o}C)
- Humidity 70/90% RH (Day/night $\pm$ 5% RH)
- Photoperiod 14 hours
- Lighting 153 Wm^{-2} supplied to each room by 4 x 1000 w tungsten halogen lamps and 4 x 1000 w Sylvania "Metalare" high pressure discharge lamps.
- Photosynthetically active radiation in the 400-700 mm waveband.
- CO_2 level was monitored but was uncontrolled remaining within 310-370 ppm.
- Air flow down to plants was 0.3 - 0.5 m sec^{-1} as measured with an Alnor instrument thermoanemometer.
- Plants were fed by Hoagland's nutrient solution (Brooking, 1976) four times per day at the rate of approximately 120 ml/pot/time before the start of water stress treatment.

3.1 Experimental design

4 x 4 factorial design with 4 replications were used. The four water treatments were:

Treatment	Plant growth stages (see section 3.3.										
	V_1	V_2	-	-	R_1	-	-	R_4	-	-	R_7
1 (Control)	+	+	+	+	+	+	+	+	+	+	+
2 (Stress at early and late reprod.)	+	+	+	+	-	-	-	-	-	-	-
3 (Stress at early reprod.)	+	+	+	+	-	-	-	+	+	+	+
4 (Stress at late reprod.)	+	+	+	+	+	+	+	-	-	-	-

(+) = well watered

(-) = stress imposed to about 60% RWC.

In treatment 2, 3 and 4 when the plants reached the defined stress stage, nutrient solution was withheld. No water was given until the leaves at the top of the plant reached RWC approximately 60%. At this point each pot was given 80 mls of nutrient solution and the pots were weighed. To maintain the plant water content at about this level the pots were watered to this weight daily. In treatment 1 and treatment 3 plants were fed at the rate of approximately 120 ml/pot/time 6 times per day from growth stage R_4.

3.2 Plant material

Cultivars Evans, Geiso and Maple Arrow were the early maturity cultivars which adapted to the Northern part of United States and Canada. These cultivars were used in some field trials in New Zealand (Hume, *pers. com.*).

Cultivar S.J.4 was selected and developed in Thailand. The region where S.J.4 is most commonly used has a day length of 12½ hours.

3.3 Description of plant growth stages

The soybean growth stages as described by Fehr *et al.* (1971) had been used in this experiment. The following description of growth stages are used in this thesis:

Stage no.	Growth description
V_3	three nodes on main stem beginning with unifoliate node.
R_1	One flower at any node.
R_4	Pod 2 cm long at one of the four uppermost nodes with a completely unrolled leaf.
R_7	Pod yellowing 50% of leaves yellow, physiological maturity.
R_8	95% of pod brown, harvest maturity

3.4 Destructive harvest

One plant/cultivar/water treatment was randomly harvested every week. Cultivar S.J.4 had not been harvested in weeks 6, 7, 10, 12 and 13, because this cultivar took about 18 weeks to reach stage R7. Only 12 plants per cultivar were used for destructive harvest.

At each harvest, total plant dry weight, shoot dry weight, pod dry weight, number of branches and leaf area were measured.

3.5 Plant and soil water status

Relative water content (RWC) and soil moisture content (SMC) had been measured.

Relative water content (RWC):

At each destructive harvest two samples of two leaf discs (1 cm diameter) from first fully expanded leaf were cut from each plant. RWCs were measured according to the method described by Barrs and Weatherley (1962) after floating the leaf discs in distilled water for 2 hours.

Soil moisture content (SMC)

Two samples of pot "mixture" from pots that were destructive harvested were collected. SMCs were measured by gravimetric method according to that described by Squire *et al*. (1981).

3.6 Final harvest

One plant/replication/cultivar/water treatment was harvested. The following plant characters, yield and yield components:plant length, number of node, number of node with pod, pod weight, seed weight, number of pod, average seed weight, number of seeds per pod; were measured. Those plant characters and yield components were measured only from the main stem.

3.7 Drought tolerance test

The method by Sullivan and Ross (1979) was used (Appendix 3). This test had been done three times, firstly when plants reached growth stage V_3, secondly at growth stage R_1 and finally during the stress period.

Analysis of variance of injury percentage between cultivars with three replications was done. The correlation between mean injury percentage and percent yield relative to control the mean yield of three stress treatments, was calculated.

3.8 Statistical analysis

3.8.1 Curve fitting

The growth for each cultivar was described by regressing total plant dry weight against time (days from sowing). Initial plots indicated that it had asymtotic curvilinear response and the following growth functions were applied to the data.

1. Logistic equation $Y = \frac{Yo}{1+e^{-(A+Bx)}}$

or $\ln\left(\frac{Y}{Yo-Y}\right) = \beta_0 + \beta_1 x$ in linear regression form.

2. Gompertz equation $Y = Yo^{A^{B^x}}$

or $\ln(y) = \ln Y_0 + \ln A(B^x)$ in linear regression form.

(Bliss 1970)

where Y = total plant dry weight

Y_0 = upper asymptote

A,B = constant

β_0, β_1 = regression estimates of the function parameters.

x = time

$\hat{Y}o$ was obtained from the semi-graphic method as described by Nelder (1961).

To make the final choice of function several criteria of best fit were considered. The criteria included relevance of curve shapes, maximixation of coefficients of determination, minimization of residuals and applicability to all 4 cultivars. Subprogram regression in SPSS (Nie *et al.* 1975) was used.

The t-test of β_0,β_1 among different curves also was done (Draper and Smith 1966). Program Regcom (Gordon unpublished) was used.

3.8.2 Analysis of variance

The two-factor factorial experiment in a randomized complete block design was used for some plant characters, yield and yield component analysis. A single-factor randomized complete block design was used with data from the drought tolerance test. In this thesis only fixed-effect model (Model I) was used, where the water treatments were precisely controlled, inferences were drawn about the particular treatments and about the particular cultivars

(Steel and Torrie 1980). The analysis was done by Genstat program (Alvey *et al.* 1977).

3.8.3 Important plant characters determining yield

The relationship between a dependent variable (yield) and the set of independent variables (plant characters) could be investigated by the use of multiple regression and partial correlation analysis.

The objectives of using multiple regression were to discover which plant characters were related to yield and to rate the plant characters in order of their importance in determining yield in two ways

(i) explained variation (coefficient of determination)

(ii) prediction (standardized regression coefficient)

The standardized multiple regression of yield against plant characters was used. The model was

$$Yi = \beta_0 x + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \text{------} \beta_k x_k + \varepsilon_i$$

where

Yi = the i^{th} observation of dependent variable (yield)

$\beta_o x$ = the mean Y for the population Y of set of x's $x_1 \ldots\ldots x_k$

X = the independent variable. The subscript i...k identify each of these independent characters.

β = the slope of the regression fitted by the mean of the least square technique.

Each x variable had its own.

ε_i = the independent error of the x's associated with the i^{th} observation.

The standardized partial regression coefficients were estimated as

$$b'_k = b_k \frac{Sk}{Sy}$$

where b'_k = the standardized partial regression coefficient for k^{th} trait

b_k = the partial regression coefficient for k^{th} trait

S_k = the standard deviation of X_k

S_y = the standard deviation of Y.

(Steel and Torrie 1980)

The stepwise procedure as described by Draper and Smith (1966) was used. In this procedure independent variables are entered only if they meet certain statistic criteria (in this case F-ratio for variables not yet in the equation = 0.01, and proportion of the variance of that variable not explained by the independent variables already in equation (tolerance) = 0.001). The order of inclusion is determined by the respective contribution of each variable to explained variance.

The other way to evaluate the contribution of independent variables to the variation of the dependent variable is to look at correlations between two variables where all others are fixed (Steel and Torrie 1980). Partial correlation coefficient can be calculated by the following formula.

$$\gamma 12.3 = \frac{\gamma 12 - \gamma 13 \gamma 23}{\sqrt{(1-\gamma_{13}^2)(1-\gamma_{23}^2)}}$$

where $\gamma 12.3$ = correlation between variables 1 and 2 the third variable is held constant.

γ's to the right of the equal signs are zero-order correlation.

The relative importance of different characters was measured in different ways namely: explained variation (coefficient of determination), prediction (standardized regression coefficient) and association (partial correlation). To get an overall indication of the importance of these characters, principal component analysis was used to combine the three aspects of importance. The increment R^2, standardized regression coefficient, and partial correlation from each component were expressed as ratios to base value (which arbitrarily was the value from weight of 20 seeds). These were used as attributes in the principal component analysis.

The correlation matrix of the standardized variables R was calculated. The solution is based on determinental equation

$$|(R - \lambda I)V| = 0$$

where λ = Lagrange multiplier (the eigenvalues in this case)

I = identity matrix

V = eigenvector

(Cooley and Lohnes, 1971)

The first principal component is generated such that it had maximum correlation with all of the standardized variables and accounts for a large portion of the total variance of the data. From the variance remaining in the data after the removal of the first principal component a second principal component is extracted which is completely uncorrelated (orthogonal) with the first principal component. The procedure is repeated until all the variance of the data is accounted for (Broschat 1979).

The factor structure matrix which given the correlations between the original variables and the principal component is the primary interpretative device in this analysis. The first principal component often is a "general factor" one, whose coefficients are all positive when the solution is based upon a table of positive correlation in factor structure matrix. (Cooley and Lohnes, 1971).

The analysis in this section was done, using the SPSS program (Nie *et al.* 1975).

3.8.4 Genotype x environment interaction

3.8.4.1. Regression analysis

In this analysis genotype x environment interactions have been considered as linear functions of the environment. For each cultivar a linear regression of individual yield on the mean yield of all cultivars for each treatment was computed (Finlay and Wilkinson 1963). Because the individual cultivar yields were plotted against the mean of all the cultivar yields the population mean had a regression coefficient of 1.0. So the hypothesis $\beta_1 = 1$ was tested with each cultivar.

3.8.4.2 Discriminant analysis

This multivariate technique was purposed to combine several characters to the index of cultivar performance in each treatment. Discriminant analysis aims at distinguishing between two or more groups on the joint basis of several attributes. The model is

$$Y = V'x$$

This is based on

$$\lambda = \left. \frac{V'AV}{V'WV} \right| \quad \text{maximum}$$

Subject to the constraint that $V'V = I(q)$

Here A = matrix of among-groups sum of square and cross-products

W = matrix of within-groups sum of square and cross-products

X = the matrix of original scores

Y = the matrix of discriminant scores

λ = the ratio shown earlier

. = the vector of q eigenvalues from the q discriminant function.

$I(q)$ = the identify matrix of order q

Maximisation of λ amounts to maximum discrimination amongst two or more groups taking into account all characters jointly (including variances and co-variances). (Cooley and Lohnes, 1971).

This analysis was done separately in each treatment. The mean of the first discriminant score was the index cultivar performance. To get the overall performance of cultivars, these values were used as attributes in principal component analysis (as described in section 3.8.3).

The analysis in this section was done by using SPSS program (Nie *et al*. 1975.)

CHAPTER IV

RESULTS

The results are presented in six main sections.
These are:

4.1 Plant and soil water status

4.2 Plant growth and development

4.3 Reproductive yield and yield components

4.4 Relative importance of selected plant characters in determining yield

4.5 Drought tolerance test

4.6 Genotype x environment interaction.

4.1 Plant and Soil Water Status

Average relative water content (RWC) and soil moisture content (SMC) for the 4 soybean cultivars are presented in figure 1a and b. Since the data point represented only 1 sample, no attempt was made for a statistical analysis of the data. By and large RWC of stressed plants ranged from 62 to 75% and SMC 8 to 11% whereas in well watered control plants the RWC ranged from 87 to 96% and SMC 16 to 24%.

4.2 Plant Growth and Development

In this section the results are presented in two main parts (i) total plant dry weight and (ii) the other plant characters.

4.2.1 Total plant dry weight

Logistic curves were successfully used to fit the total dry weight of the control plants (treatment 1) and treatment 3 plants against time (Figures 2a, b, c and d).

Attempts to fit data from treatment 2 and treatment 4 were also made

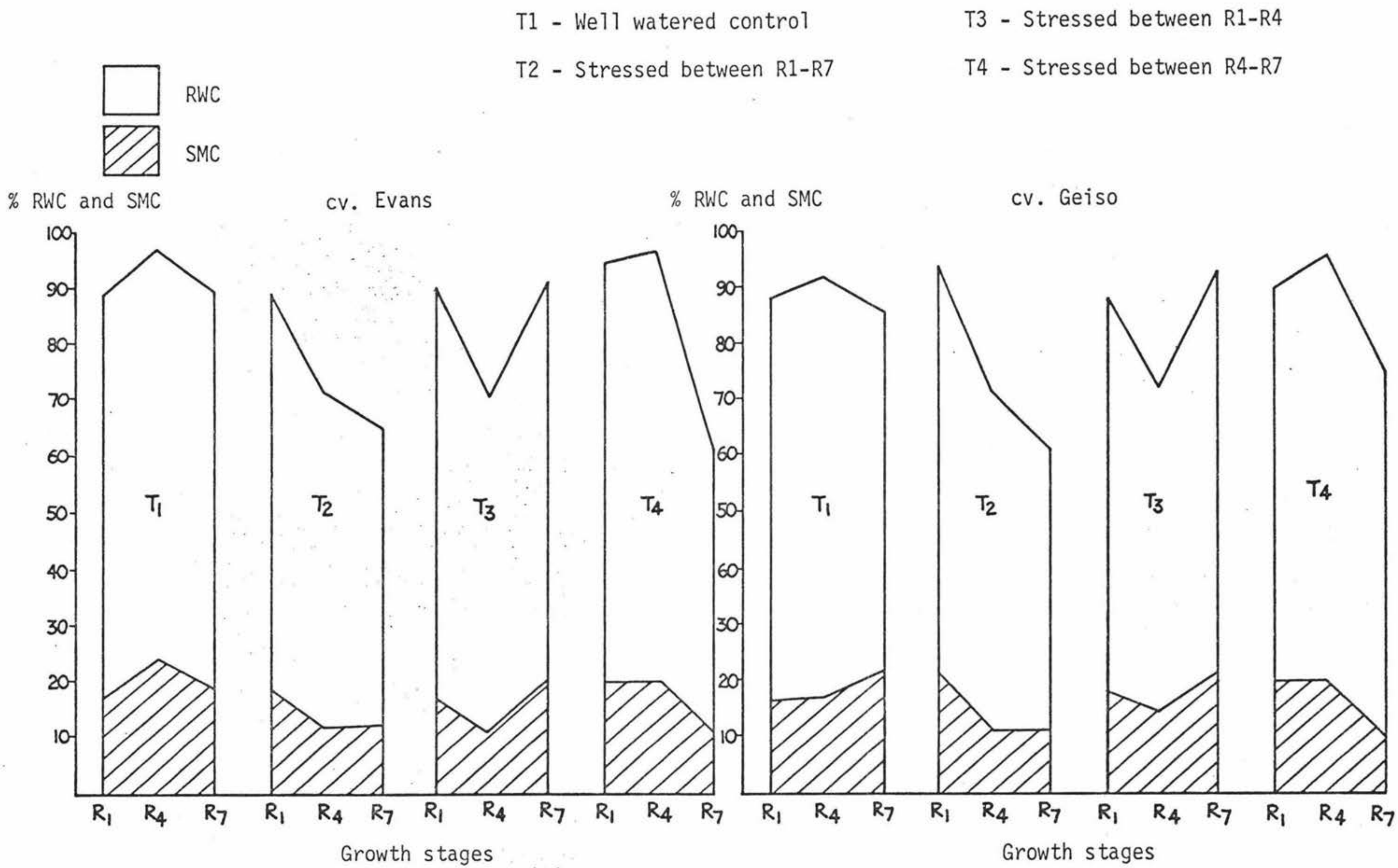


Figure 1a. Relative water content (RWC) and soil moisture content (SMC) at different growth stages in different treatments for cultivars Evans and Geiso.

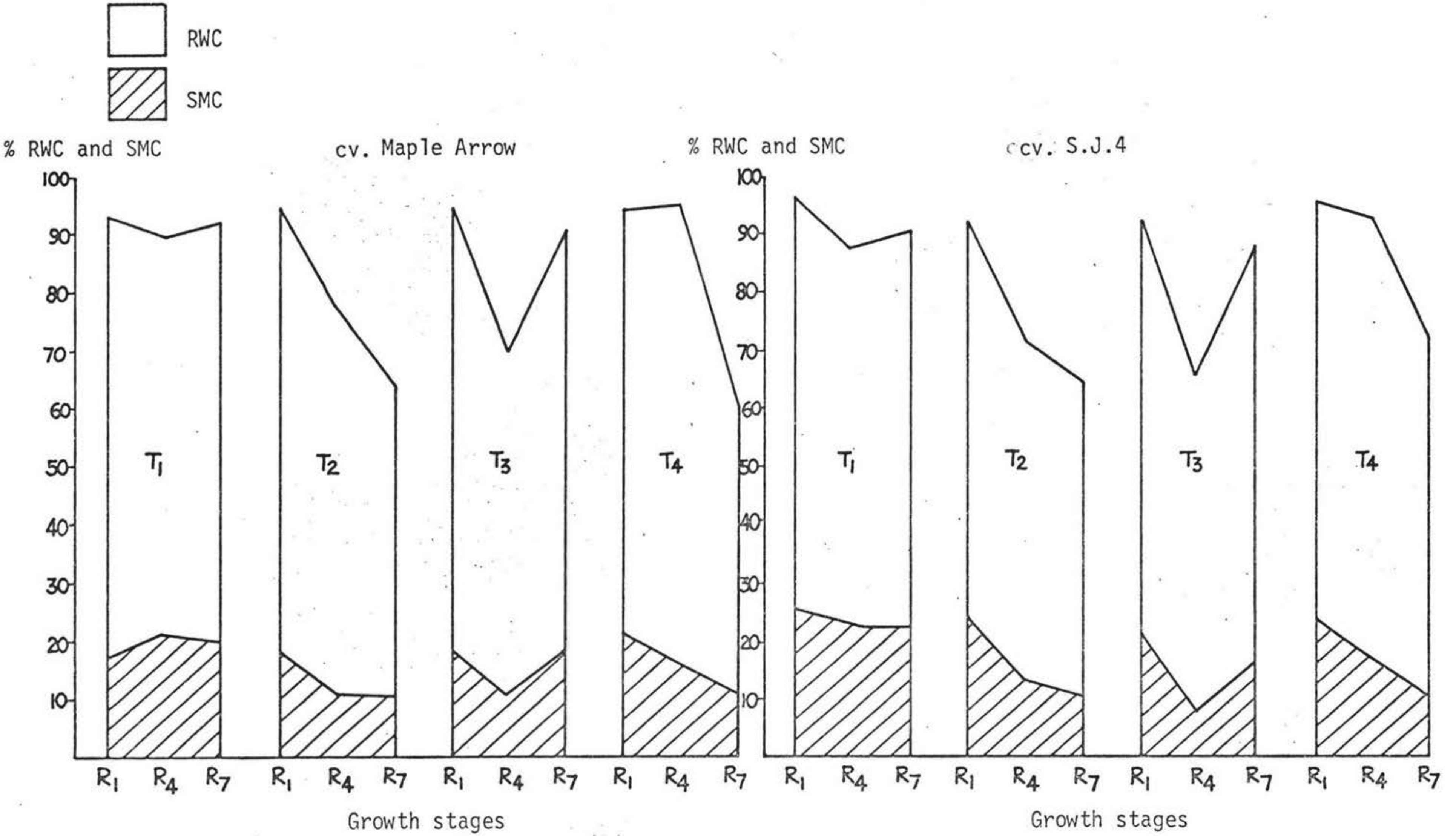


Figure 1b. Relative water content (RWC) and soil moisture content (SMC) at different growth stages in different treatments for cultivars Maple Arrow and S.J.4.

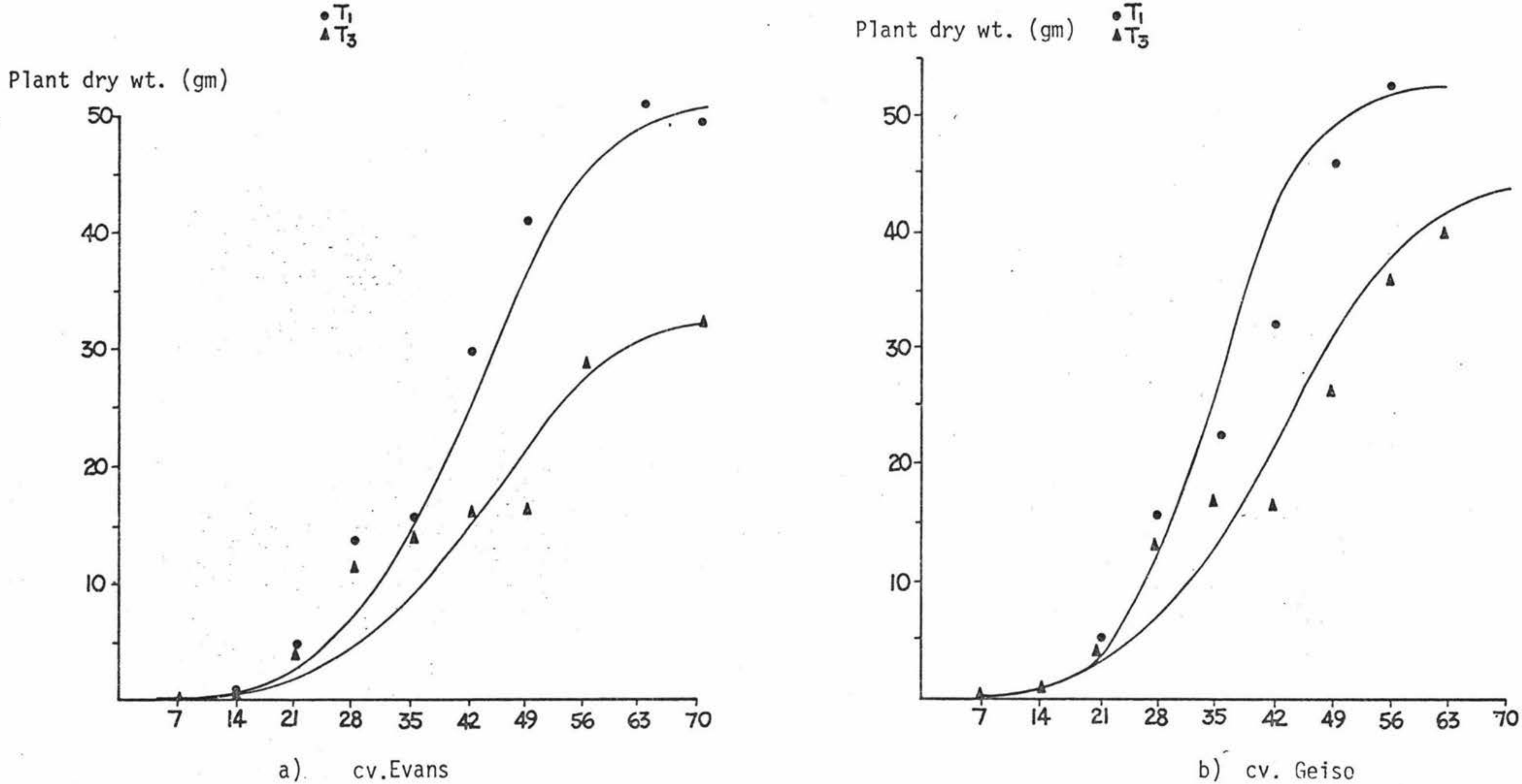
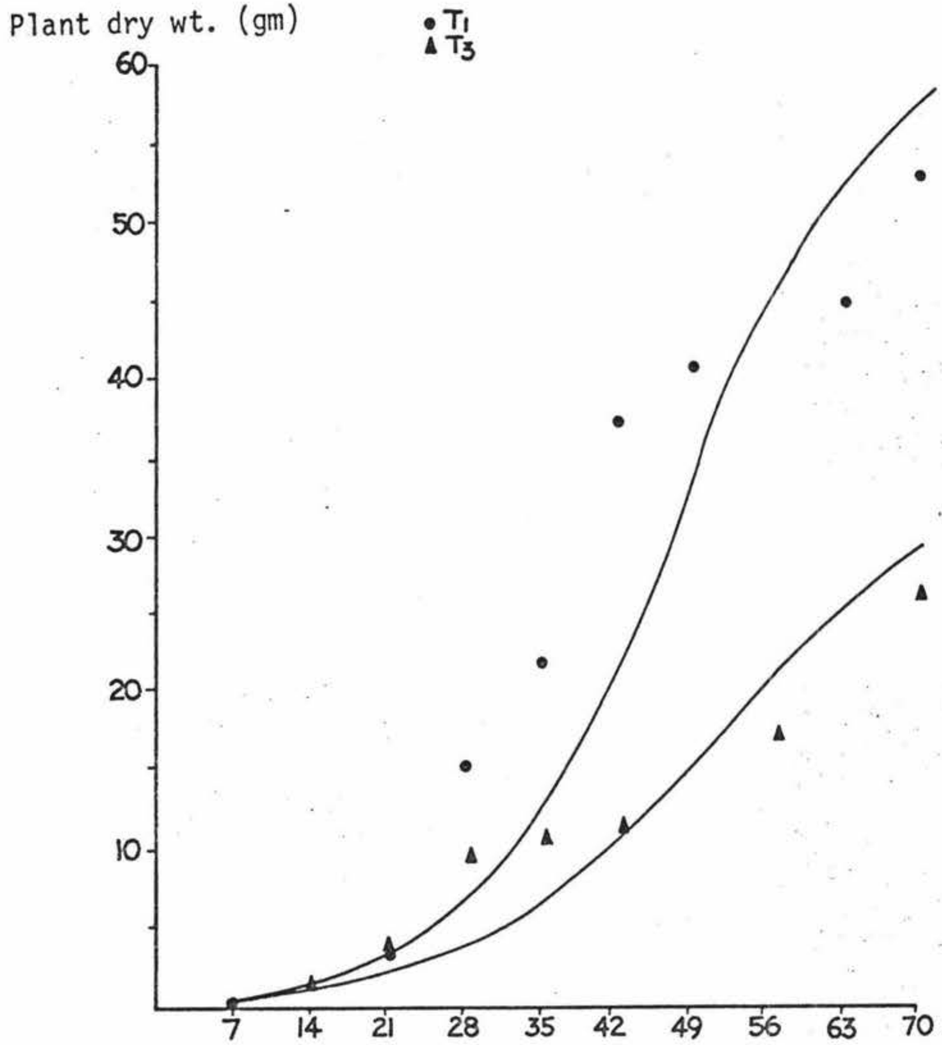
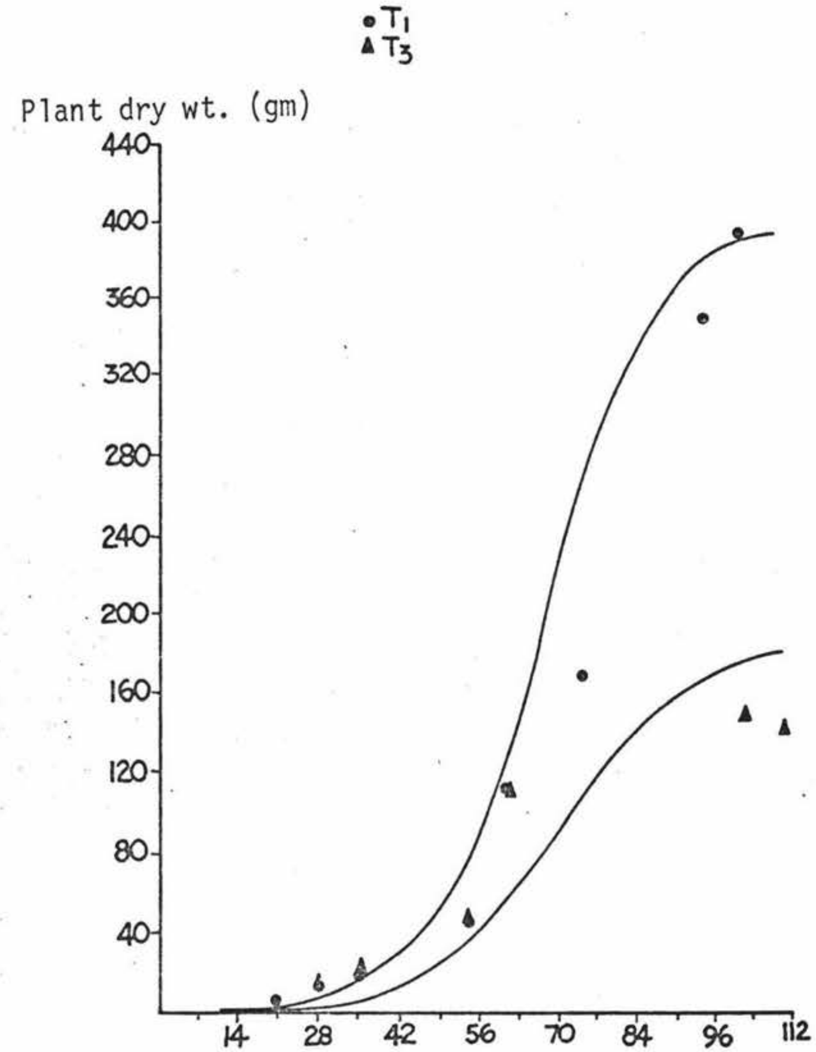


Figure 2. Growth curves of cultivars a) Evans b) Geiso c) Maple Arrow d) S.J.4 from Treatments 1 and 3.



c) cv. Maple Arrow



d) cv. S.J.4

(Figure 3). Partly because of the scattered nature of the data sets and partly because of the real effects of water stress, no single curve could satisfactorily fit these data sets i.e. coefficients of determination (R^2) were very low (Appendix 2). To separate these data sets into two or more components based on stress periods and fit a single curve into each component was also unsatisfactory, because of insufficient data points within each component. Hence only results from treatments 1 and 3 will be presented.

In treatments 1 and 3 for cultivars Evans, Geiso and Maple Arrow, the rapid growth rate commenced after day 21 whereas in S.J.4 it was after day 42 (Figure 2a, b, c and d). The asymtotes ($\hat{Y}o$) were of further interest because these $\hat{Y}o$ indicated the potential total plant dry weight of these cultivars. Under treatment 1, $\hat{Y}o$ in S.J.4 (408 gm/plant) was approximately eight times greater than those of the other cultivars (between 50-60 gm/plant). When the $\hat{Y}o$ were compared between treatments 1 and 3, it was evident that for each cultivar the well watered plants (treatment 1) had much higher total plant dry weight than those of treatment 3.

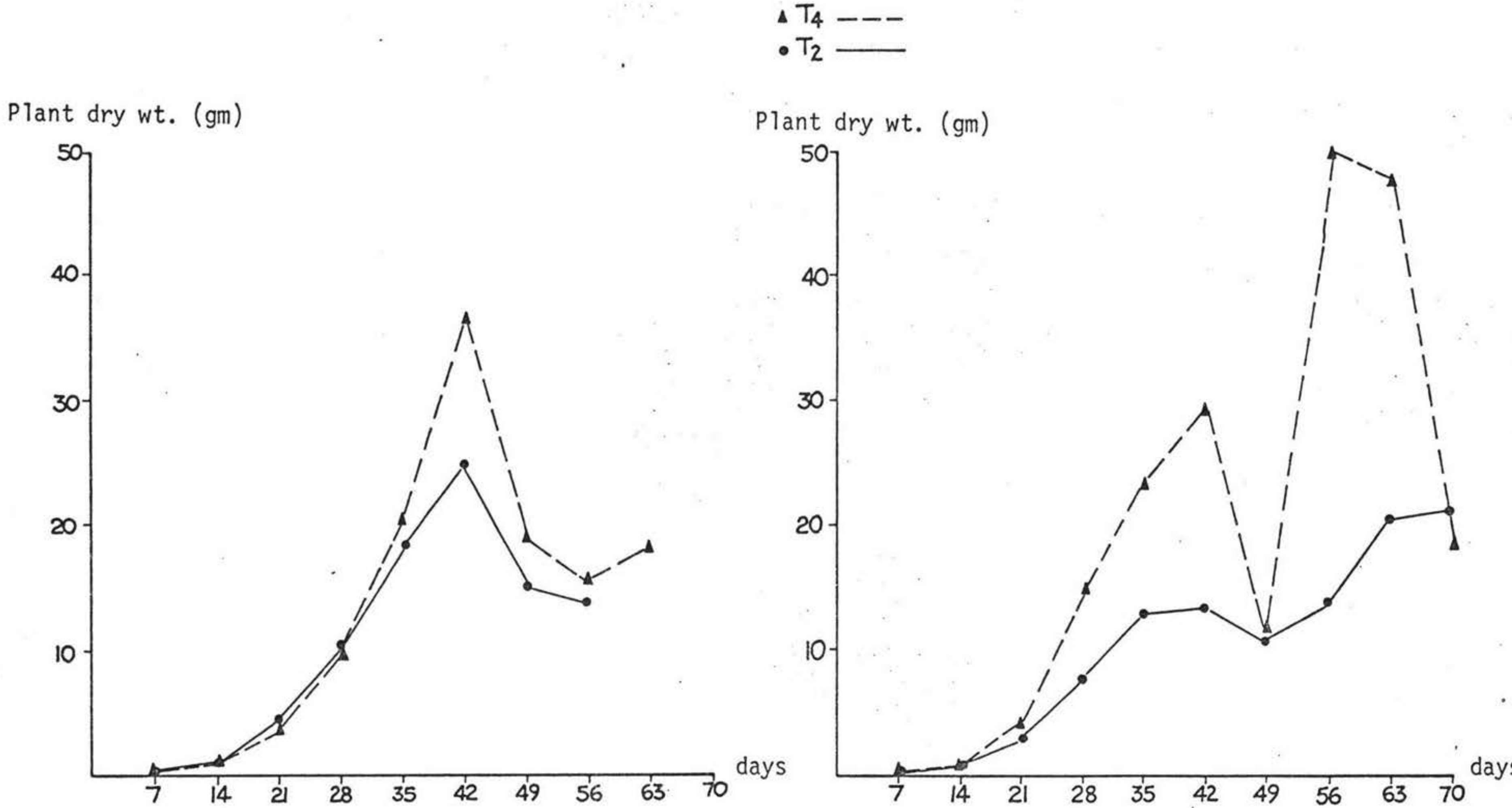
4.2.1.1 Comparison between curves

Information from the linear regression $\left(\ln\left(\frac{Y}{Yo-Y}\right) = \beta_0+\beta_1 x\right)$ for each cultivar are presented in Tables 1 and 2. β_0 and β_1 are respectively the value of constants A and B in the equation

$$Y = \frac{Yo}{1+e^{-(A+Bx)}} \qquad \text{(Section 3.8.1)}$$

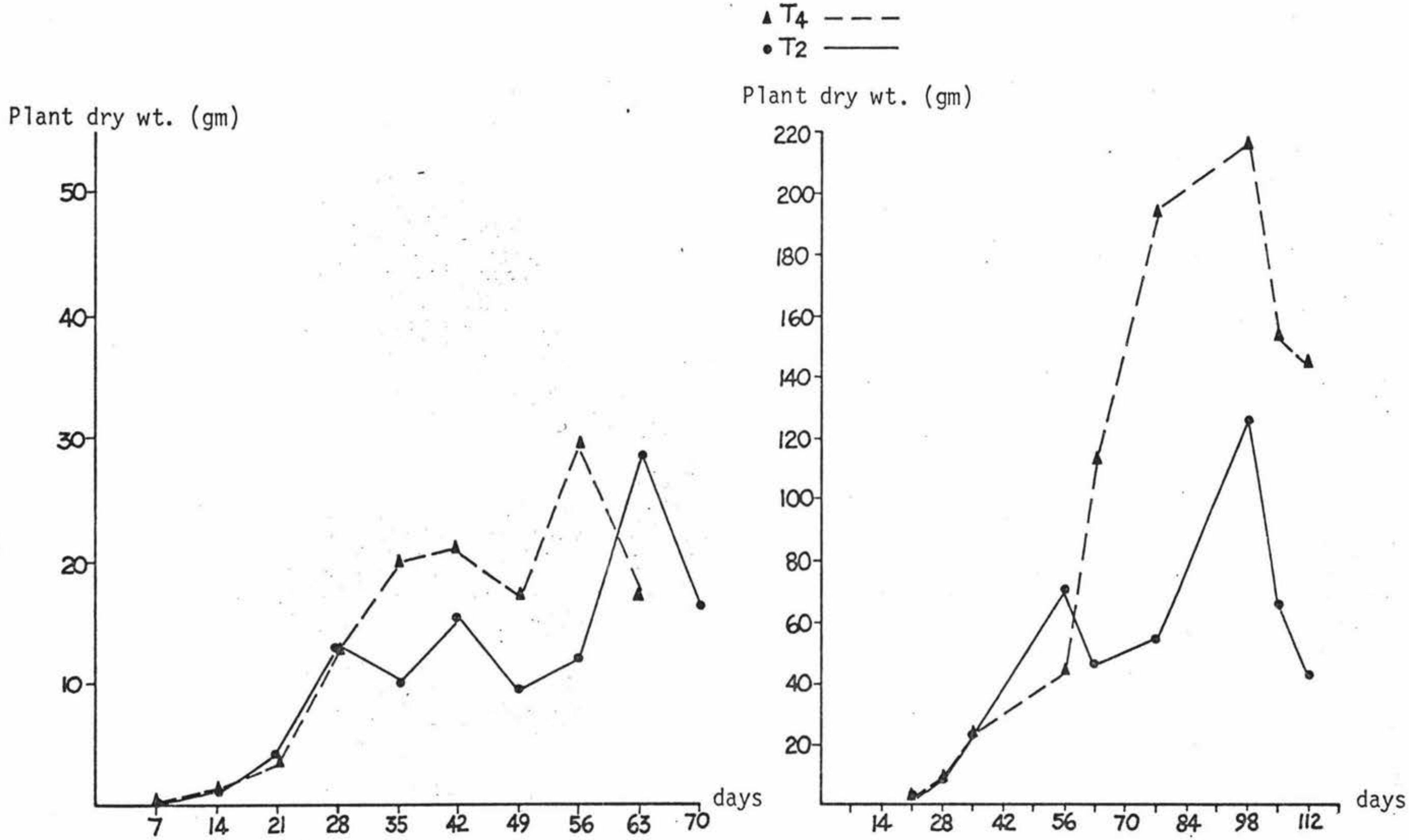
Both β_0 and β_1 affect rate of change in total plant dry weight where β_1 is of further interest because it is the relative growth rate (Bliss 1970).

The comparison of relative growth rates (β_1) amongst cultivars within the same treatment indicated that in the control treatment Geiso had the



a) cv. Evans b) cv. Geiso

Figure 3. Plant dry weight plotted against time for cultivars a) Evans b) Geiso c) Maple Arrow d) S.J.4 from Treatment 2 and 4.



c) cv. Maple Arrow

d) cv. S.J.4

Table 1 Information from linear regression $\ln\left(\frac{Y}{Y0-Y}\right) = \beta_0 + \beta_1 x$ for the 4 soybean cultivars from treatment 1.

Cultivars	β_0	Standard error of β_0	β_1 1/	Standard error of β_1	Asymtote ($\hat{Y}_0$) (gm/plant)	R^2
Evans	-5.762	0.506	0.137 b	0.0116	52.20	0.945
Geiso	-6.934	0.667	0.200 a	0.019	52.50	0.949
Maple Arrow	-5.428	0.659	0.113 b	0.016	63.75	0.880
S.J.4	-7.856	0.698	0.115 b	0.012	408.99	0.925

1/ statistics sharing the same letter are not significantly different ($P \leq 0.05$)

Table 2 Information from linear regression $\ln\left(\frac{Y}{Y0-Y}\right) = \beta_0 + \beta_1 x$ for the 4 soybean cultivars from treatment 3.

Cultivars	β_0	Standard error of β_0	β_1 1/	Standard error of β_1	Asymtote ($\hat{Y}_0$) (gm/plant)	R^2
Evans	-5.193	0.517	0.123 a	0.013	33.81	0.931
Geiso	-5.273	0.465	0.120 a	0.012	45.50	0.936
Maple Arrow	-4.590	0.548	0.089 b	0.013	34.88	0.862
S.J.4	-6.487	0.497	0.089 b	0.008	195.00	0.940

1/ statistics sharing the same letter are not significantly different ($P \leq 0.05$)

highest relative growth rate (0.02 gm/gm/day) and it was significantly different from the others (Table 1). Whereas in treatment 3 (table 2) relative growth rates of Evans and Geiso were significantly greater than Maple Arrow and S.J.4.

Comparisons between treatments 1 and 3 for values of β_0 and β_1 are presented in Table 3. The relative reduction in β_1 and $\hat{Y}o$ (Table 3) are compared across the cultivars. Geiso had the greatest relative reduction in β_1 between treatments 1 and 3 (40%) but its $\hat{Y}o$ was only reduced by 13%. On the other hand in S.J. 4, β_1 was reduced by 22% but its $\hat{Y}o$ was reduced by 52%.

4.2.2 The other plant characters

4.2.2.1 Days required to reach growth stages R1, R4 and R7

The average number of days required from sowing to growth stages R1, R4 and R7 are presented in Table 4. On the average for cultivars Evans, Geiso and Maple Arrow, the interval between R1 and R4 (stress treatment 3) was about 10 days and between R4 to R7 (stress treatment 4) was about 53 days. However, in S.J.4 it took 34 and 59 days from R1 to R4 and from R4 to R7 respectively.

4.2.2.2 Leaf area per plant

Average leaf area per plant measured between growth stages R1 to R4 and R4 to R7 for the 4 soybean cultivars in 4 water treatments are presented in table 5. Leaf area per plant was reduced in all stress treatments. S.J. 4 had the largest leaf area per plant in all treatments, especially during growth stage R4 to R7 under well watered conditions (Treatment 1). It had about ten times more leaf area per plant than those of the other three cultivars.

4.2.2.3 Plant length

Although stress treatments were only imposed during the reproductive

Table 3 T-test (1tailed) of β_0,β_1 within cultivars across treatments 1 and 3 and the relative reductions of β_1 and the asymtote.

Cultivar	β_1 t-test	Significance	β_1 t-test	Significance	Relative Reduction (%) of	
					β_1	Asymtote ($\hat{y}_0$)
Evans	0.79	NS	0.80	NS	10.0	35.2
Geiso	2.04	*	3.63	***	40.3	13.3
Maple Arrow	0.98	NS	1.16	NS	21.2	45.3
S.J.4	1.60	NS	1.84	*	22.5	52.2

Table 4 Average number of days from sowing to growth stages R1, R4 and R7 (final harvest).

Cultivars \ Growth Stages	R1	R4	R7
Evans	25±0.7	35±1.2	86±9.5
Geiso	26±0.9	36±1.1	89±8.3
Maple Arrow	24±1.5	35±1.3	90±9.2
S.J.4	50±2.4	84±1.9	143±11.4

Table 5 Mean leaf area per plant of 4 soybean cultivars from 4 water treatments (cm^2).

Treatment	Between growth stages	Evans	Geiso	Maple Arrow	S.J.4
T1	R1-R4	2465±447	3583±628	2630±122	10887±6897
	R4-R7	1461±391	2712±1145	1982±1192	25526±9849
T2	R1-R4	1751±338	1485±496	1468±1159	4481±2482
	R4-R7	960±391	690±185	571±325	3926±2733
T3	r1-R4	1637±585	2476±830	1772±997	4761±2026
	R4-R7	1600±162	1568±515	1094±495	12275±3652
T4	R1-R4	2685±961	3404±809	2553±85	10063±1400
	R4-R7	737±298	1508±1004	603±87	6898±3096

growth stages, the effect on final plant length was prominent. Both the between treatment and between cultivar differences were significant (Table 6). Under water stress, plants in treatments 2 and 3 were significantly shorter than those of treatments 1 and 4. Cultivar S.J.4 had the longest length (184 cm) which was at least 50 cm longer than the others. No significant cultivar x treatment interaction was found in this character. Photographs of the 4 soybean cultivars from the 4 water treatments are presented in Plates 1a, b, c and d.

4.2.2.4 Number of branches

The average number of branches/plant (along main stem) from the 4 soybean cultivars are presented in table 7. For cultivars Evans, Geiso and Maple Arrow water stress treatments had little effect on the number of branches/plant, whereas in S.J.4 the number of branches/plant was severely reduced in treatment 2. Under treatments 1, 3 and 4, S.J.4 had about twice the number of branches than those of cultivars Evans, Geiso and Maple Arrow.

4.2.2.5 Number of nodes

As can be seen from table 8, well watered control plants had the highest number of nodes per plant (along main stem) followed closely by treatment 4. By contrast, treatment 2 had the lowest number of nodes per plant and it was significantly different from all the other treatments. Cultivar S.J.4 had the highest number of nodes which was about 61% more than those of the other cultivars.

4.2.2.6 Percentage of nodes with pods

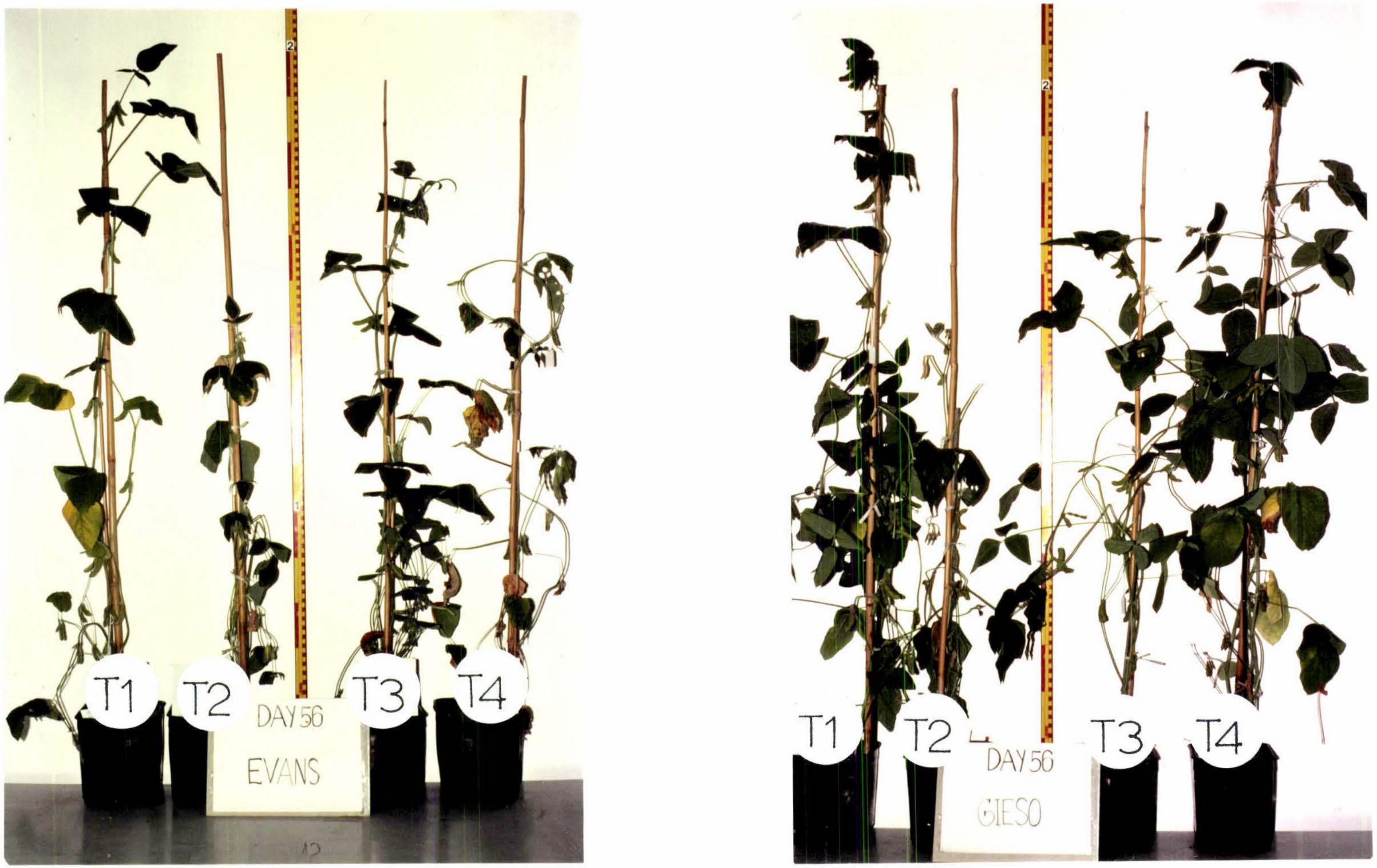
The average percentage of nodes with pods from the 4 water treatments (Table 9) depended on the duration of water stress. The ranking from the highest to the lowest percentage of pod bearing node were treatments 1, 3, 4 and 2. S.J.4 had the lowest percentage of nodes with pods (along

Table 6 Mean final plant length (cm) for a) water treatments and b) cultivars.

a) Water treatments	T1	T2	T3	T4
1/	161.1a	120.6b	130.6b	150.0a
b) Cultivars	Evans	Geiso	Maple Arrow	S.J.4
2/	114.2c	124.4bc	139.1b	184.6a

	treatment	cultivar
Significance	**	**

1/, 2/ means sharing the same letters are not significantly different compared by LSD. ($P \leq 0.05$)



a b

Plate 1. Photographs of the 4 soybean cultivars from the 4 water treatments

c

d

Table 7 Average number of branches per plant of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4
T1	4 ± 1.2	5 ± 0.5	4 ± 1.4	10 ± 4.0
T2	4 ± 0.7	4 ± 0.7	4 ± 1.1	3 ± 2.2
T3	4 ± 1.2	4 ± 1.5	4 ± 0.7	7 ± 2.7
T4	4 ± 1.5	4 ± 1.3	4 ± 1.7	7 ± 3.2

Table 8 Mean number of nodes (along main stem) of a soybean cultivars from 4 water treatments.

Cultivars / Treatments	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	11.00	12.00	14.25	18.75	14.00a
T2	9.50	9.50	10.00	16.00	11.25c
T3	10.25	11.25	11.00	18.00	12.63b
T4	11.25	11.00	12.50	18.25	13.25ab
Mean 2/	10.50c	10.94c	11.94b	17.75a	

	cultivar	treatment	cultivar x treatment
Significance	**	**	NS

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$).

Table 9 Percentage of nodes with pods (along main stem) of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	84.2	74.7	89.6	59.2	76.9a
T2	60.3	58.1	67.5	8.5	48.6d
T3	75.9	71.0	76.7	46.9	67.6b
T4	71.5	45.4	83.8	33.0	58.4c
Mean 2/	73.0a	62.3b	79.4a	36.9c	

	cultivar	treatment	cultivar x treatment
Significance	**	**	NS

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$).

main stem) or about 50% that of the other cultivars, whereas Maple Arrow had the highest percentage (79.4%) followed closely by Evans (73%).

4.2.2.7 Number of pods per node

In this character, plants which were subjected to the longest period of water stress (treatment 2) had only about half of the number of pods per node when compared with those of the control plants (Table 10). Although treatments 3 and 4 were not significantly different from each other they were significantly different from treatments 1 and 2. Significant cultivar x water treatment interaction was found in this character. Cultivars Geiso and S.J.4 had the greatest contrast, particularly in treatment 2.

The Detail of analysis of variance in this section are presented in Appendix 4.1 to 4.4

4.2.2.8 Ratio of pod dry weight/above ground biomass

The pod dry weights from the 4 treatments were measured from the time of pod formation. The ratio of pod dry weight/above ground biomass plotted against time from the 4 soybean cultivars are presented in Figure 4. S.J.4 had the lowest ratio of pod dry weight/above ground biomass for all the treatments. Amongst the three other cultivars (*viz* Evans, Geiso and Maple Arrow) the trend of the ratio was quite similar; although under treatment 2, Geiso was clearly lower than that of the others.

4.3 Reproductive Yield and Yield Components

In this section the result has been divided into 3 parts (i) total pod and seed yield (ii) main stem seed yield and (iii) yield components.

4.3.1 Total pod and seed yield

The effects of water stress resulted in substantial reduction in both pod weight and seed weight per plant (Table 11 and 12) and the differences were significant ($P \leq 0.05$). Amongst the water stress treatments, treatment 3 had the highest seed yield (table 11) but was still only 50%

Table 10 Mean number of pods per node (along main stem) of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	3.525	3.800	4.100	2.675	3.525a
T2	2.475	1.950	2.375	0.450	1.813c
T3	2.675	2.575	2.575	3.225	2.763b
T4	2.625	2.350	3.225	1.975	2.544b
Mean 2/	2.825a	2.669a	3.069a	2.081b	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing same letter are not significantly different compared by LSD ($P \leq 0.05$).

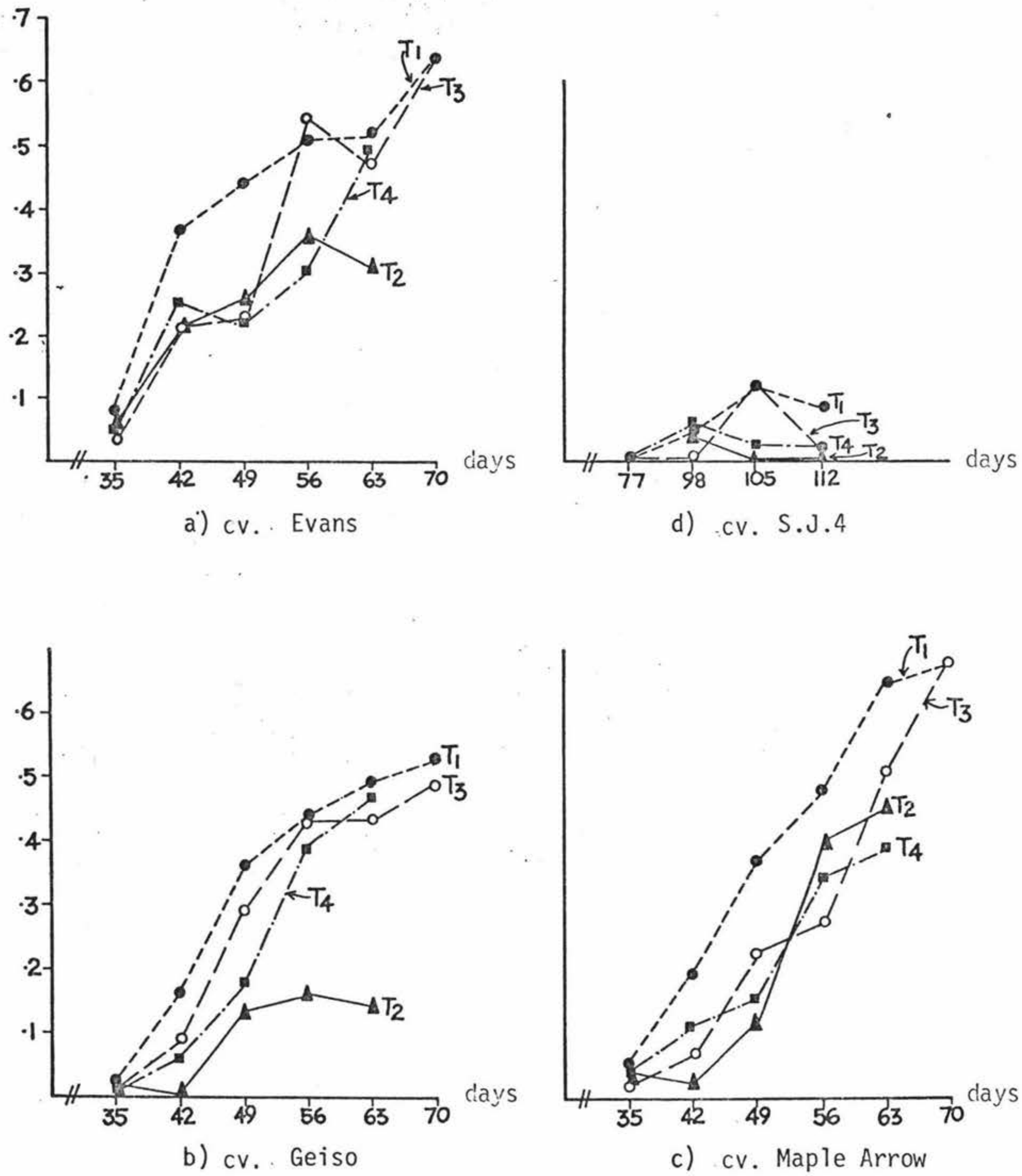


Figure 4. Ratio of pod dry weight and above ground biomass of cultivars a) Evans b) Geiso c) Maple Arrow d) S.J.4 from 4 water treatments.

Table 11 Mean pod weight (gm) per plant of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	33.1	36.1	41.8	97.8	52.2a
T2	5.9	4.5	9.5	1.5	5.3d
T3	16.7	23.8	19.7	47.3	26.9b
T4	9.5	6.4	17.7	18.3	13.0c
Mean 2/	16.3b	17.7b	22.1b	41.2a	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing same letter are not significantly different compared by LSD ($P \leq 0.05$).

Table 12 Mean seed weight (gm) per plant of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	24.2	26.5	29.8	57.4	34.5a
T2	4.2	2.6	7.0	0.8	3.7d
T3	11.9	19.2	13.0	24.2	17.1b
T4	6.7	4.6	12.2	9.9	8.3c
Mean 2/	11.7c	13.2bc	15.5b	23.1a	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing same letter are not significantly different compared by LSD ($P \leq 0.05$).

that of treatment 1 (Control). Seed yields in treatment 2 and treatment 4 were 10 and 24% that of treatment 1 respectively. Amongst the 4 cultivars, S.J.4 had the highest pod and seed weights, whereas in the other three cultivars pod and seed weights were similar.

Although the ranking, from the lowest to the highest yield was for treatments 2, 4, 3 and 1 respectively in all cultivars, the cultivar x treatment interaction was significantly different in both pod weight and seed weight ($P \leq 0.01$). This was probably due to the response by S.J.4 to different water treatments relative to the other cultivars. S.J.4 had much higher pod and seed weight in treatments 1 and 3. For example, under treatment 1 S.J.4 had 114% and 164% more seed and pod weights respectively than the average of the other three cultivars. In contrast, under treatment 2 S.J.4 had the lowest pod and seed weights. Furthermore, only Maple Arrow had about the same pod and seed weights from treatments 3 and 4.

4.3.1.1 Harvest Index

The ratios of total seed yield to above ground biomass (Harvest Index) are presented in table 13. Cultivar S.J.4 had the lowest Harvest Index in all treatments. In treatments 2 and 4 Harvest Indices of Geiso and S.J.4 were severely reduced when compared with those of treatments 1 and 3.

4.3.2 Main stem seed yield

Seed yields from main stem are presented in table 14. Although the ranking from the lowest to the highest seed yield was similar to that of the total seed yield (Table 12) i.e. treatments 2, 4, 3 and 1, seed yield measured from the main stem were quite different from those measured from the total plant. This was because the ratio of main stem seed weight relative to total seed weight was different for different cultivars (Table 15).

Table 13 Harvest index of the 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4
T1	.46	.50	.47	.14
T2	.26	.13	.31	.02
T3	.35	.42	.37	.12
T4	.39	.14	.52	.07

Table 14 Mean of main stem seed weight (gm/plant) of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	17.08	15.51	25.29	6.84	16.18a
T2	3.46	2.01	5.49	0.14	2.77c
T3	6.86	9.68	11.30	6.49	8.58b
T4	4.79	2.52	9.71	1.00	4.51c
Mean 2/	8.05b	7.43b	12.95a	3.62c	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$).

Table 15 Main stem weight relative to total seed weight (%) for the 4 soybean cultivars under the 4 water treatments

Treatment \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean
T1	70.6	58.5	84.8	11.9	56.5
T2	82.2	77.0	78.4	17.1	63.7
T3	57.8	50.5	87.1	26.9	55.6
T4	72.0	54.3	79.9	36.5	60.7
Mean	70.6	60.1	82.6	23.1	

S.J.4 had the lowest percentage of main stem/total seed weight in all the treatments (from 11.9 - 36.5%) whereas in the other cultivars they were between 50.5 to 87.1%.

4.3.3 Yield components

Yield components from the following equation are used in this study.

Yield (gm) = no. of pod x no. of seed/pod x average seed wt. (gm) (Adam, 1967).

The result presented in this section was measured from the main stem only.

4.3.3.1 Number of pods

Water stress had markedly decreased the number of pods in all the stress treatments (Table 16). Treatment 2 had the lowest number of pods (27.8% relative to that of the control) and it was signficantly different from the other treatments. Even under the shortest duration of water stress (Treatment 3) the pod numbers were also significantly reduced (63% relative to that of control). The cultivar x treatment interaction was significant ($P \leq 0.01$) in this component, with cultivars S.J.4 and Maple Arrow having the greatest contrast, particularly for Treatments 3 and 4.

4.3.3.2 Number of seeds per pod

A brief period of water stress (Treatment 3) did not significantly reduce the number of seeds per pod (Table 17). The reduction of this component in Treatments 2 and 4 was only 33% and 16% that of control numbers respectively. Cultivar x water treatment interaction was again significant ($P \leq 0.01$) in that, under Treatments 2 and 4, the reduction of seeds per pod in S.J.4 was greater than the reductions in the other cultivars. This led to S.J.4 having the lowest number of seeds per pod.

4.3.3.3 Average seed weight

The average seed weights are presented as weight of 20 seeds in Table

Table 16 Mean number of pods from main stem of 4 soybean cultivars from 4 water treatments.

Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	32.75	33.75	52.75	29.50	37.19a
T2	15.00	10.75	16.00	1.00	10.69d
T3	21.75	20.75	22.00	29.50	23.50b
T4	21.00	11.00	34.00	6.75	18.19c
Mean 2/	22.63b	19.06b	31.19a	16.69c	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$).

Table 17 Mean number of seeds per pod of 4 soybean cultivars from 4 water treatments.

Culivars / Treatments	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	2.250	1.975	2.150	1.850	2.056a
T2	1.675	1.250	2.025	0.575	1.381c
T3	1.725	1.950	1.975	1.900	1.888ab
T4	1.900	1.800	1.850	1.375	1.731b
Mean 2/	1.888ab	1.744b	2.000a	1.425c	

	cultivar	treatment	cultivar x treatment
Significance	**	**	**

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$).

18. Water stress treatments significantly affected the average seed weight only when the plants were subjected to water stress at pod filling stage (treatment 4) and at the entire reproductive growth stage (treatment 2). S.J.4 had the lowest average seed weight. Again, the contrast between S.J.4 and the other three cultivars caused the significant cultivar x water treatment interaction. Photographs of seeds from the 4 soybean cultivars under the 4 water treatments are presented in Plates 2a, b, c and d.

The summary for the estimated main stem yield and yield components of the 4 soybean cultivars are presented in Table 19. The result demonstrated that pod number was the major component that influenced the difference in yield between Maple Arrow, Evans and Geiso, whereas in S.J.4 all the 3 yield components were responsible in influencing the lower seed yield.

The detail of analysis of variance in this section are presented in Appendix 4.5 to 4.10.

4.3.4 The relationship between duration of stress and reduction of yield and yield components

For each cultivar the total seed yield of the stress plant was expressed as a percentage relative to that of the control plant and the value was plotted against the non-stress days which was also expressed as a percentage relative to the control treatment (Figure 5a and 5b). In order to generalise the relationship, exponential equations of the linear form

$$\ln(y) = \beta_0 + \beta_1 x$$

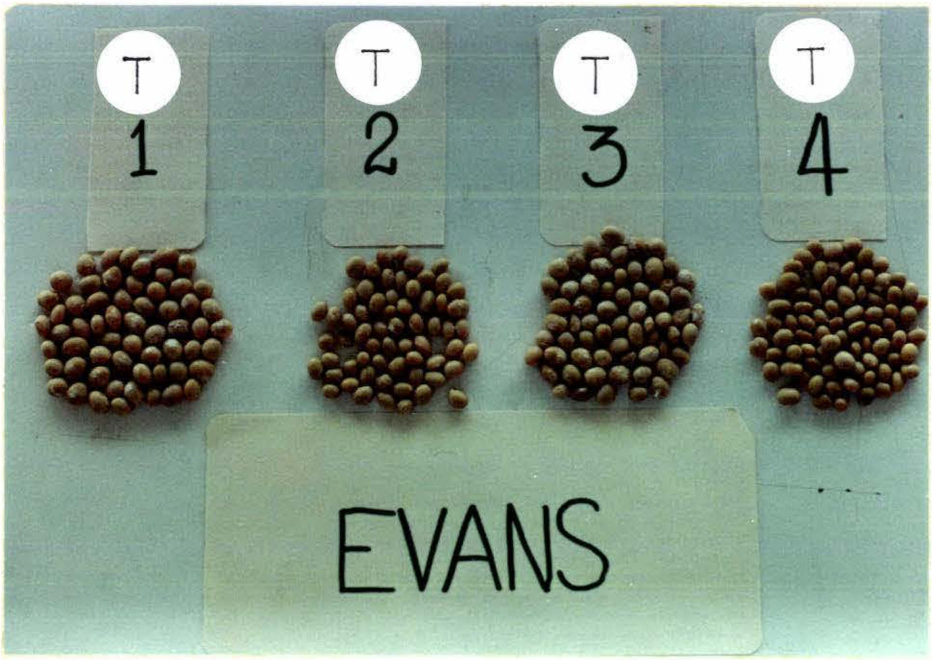
was fitted to each cultivar and presented in Figure 5a and 5b. The responses could be separated according to the different growth types. For the indeterminate growth type (Geiso and S.J.4) at 10% relative water stress (90% non-stress day) the yield was reduced by 25% (Figure 5b) whereas in the determinate growth types (Evans and Maple Arrow) relative reduction in yield was about 50% at the same level of water stress

Table 18 Mean weight of 20 seeds of 4 soybean cultivars from 4 water treatments (gm)

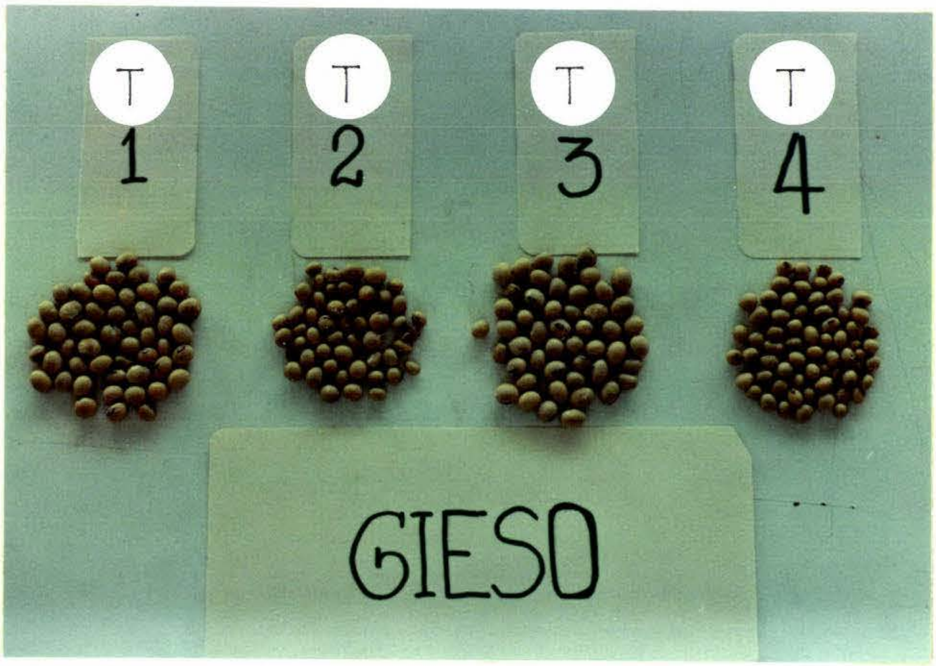
Treatments \ Cultivars	Evans	Geiso	Maple Arrow	S.J.4	Mean 1/
T1	4.667	4.685	4.565	2.578	4.124a
T2	2.423	3.132	3.068	0.925	2.387b
T3	3.763	4.677	5.120	2.225	3.946a
T4	2.370	2.520	2.908	2.327	2.531b
Mean 2/	3.306b	3.754ab	3.915a	2.014c	

	cultivar	treatment	cultivar x treatment
Significance	**	**	*

1/, 2/ means sharing the same letter are not significantly different compared by LSD ($P \leq 0.05$)

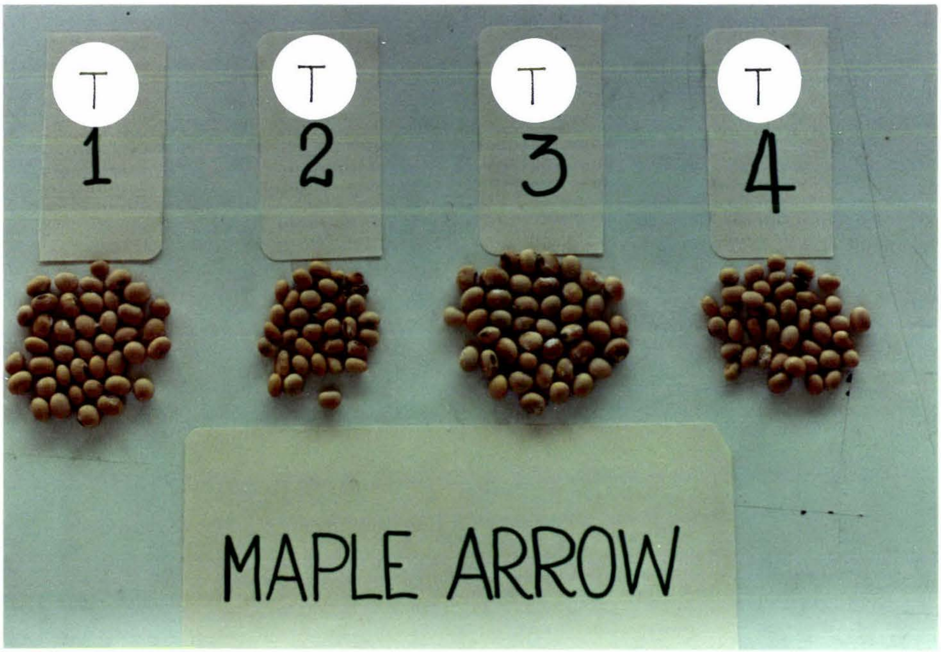


a

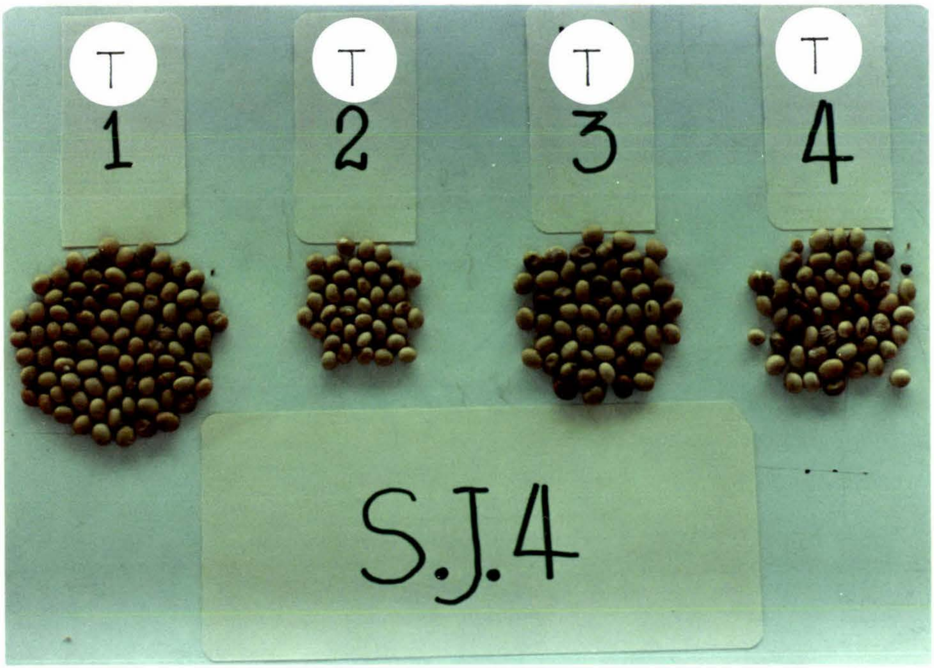


b

Plate 2. Photographs of seeds from the 4 soybean cultivars from the 4 water treatments.



c



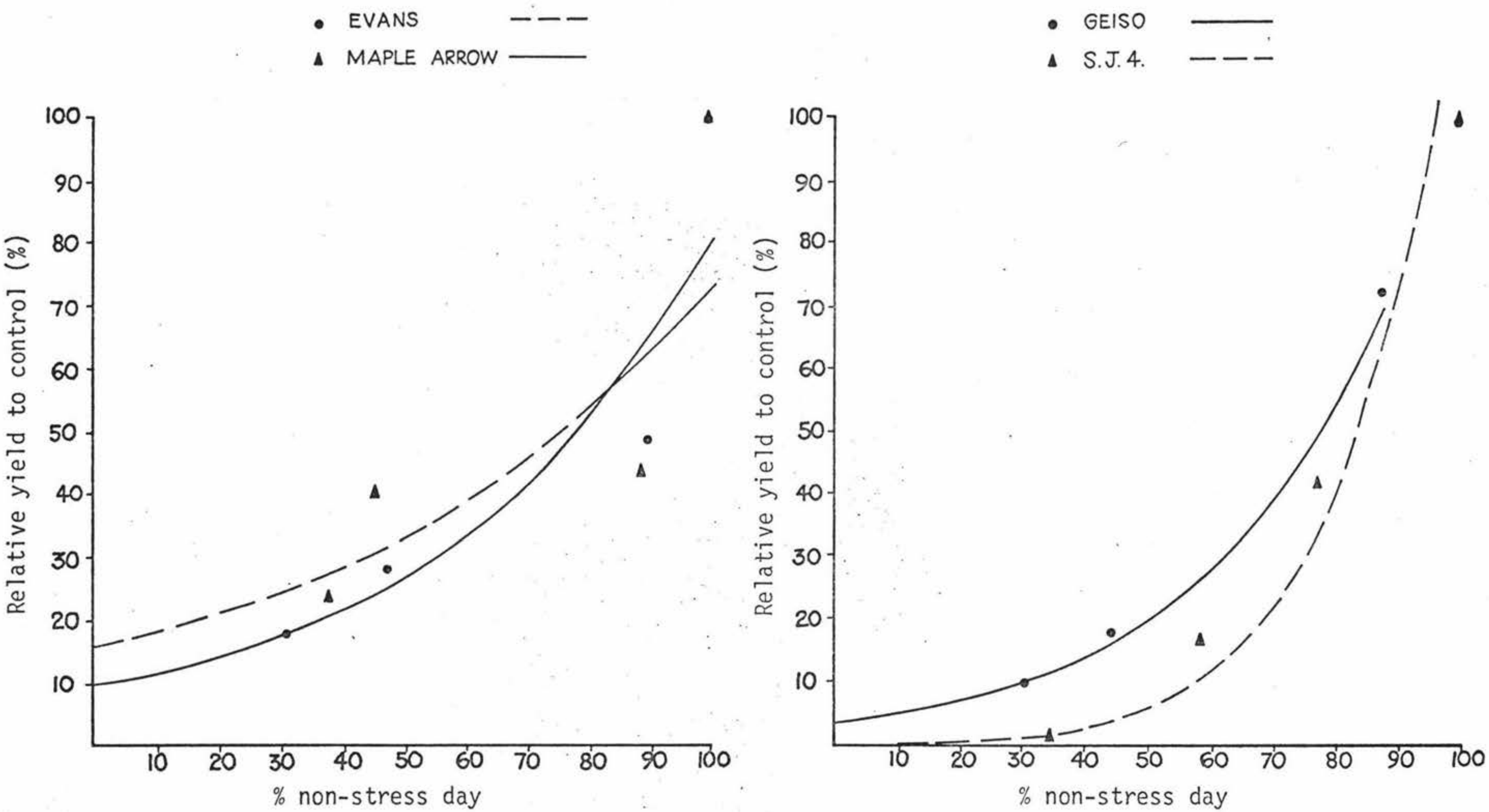
d

Table 19 Average main stem seed yield and yield components of 4 soybean cultivars.

Cultivar	Yield 1/ (gm)	Pod number	Number of seed per pod	20 seed weight (gm)
Evans	7.06 (8.05b)	22.63b	1.888a	3.306a
Geiso	6.24 (7.43b)	19.06b	1.744a	3.754a
Maple Arrow	12.21 (12.95a)	31.19a	2.000a	3.915a
S.J.4	2.39 (3.62c)	16.69b	1.425b	2.014b

1/ yield is estimated base on the equation yield (gm) = pod numbers x No. of seed/pod x Av. seed wt.(gm)

Actual yield is in parenthesis.



a) Evans & Maple Arrow b) Geiso & S.J.4

Figure 5. Curves of total seed yield expressed as % to control against non-stress days (% to control) of 4 soybean cultivars a) Evans & Maple Arrow b) Geiso & S.J.4.

(Figure 5a). When stress duration was increased further the reduction in yield was higher in the indeterminate growth type than that of the determinate growth type. The greatest contrast was between Maple Arrow and S.J.4. In Maple Arrow a 42% reduction in non-stress day resulted in only 3% reduction in yield, whilst in S.J.4 a 20% non-stress day resulted in 25% reduction in yield (Figure 5a and 5b).

Main stem seed yield and yield components (*viz* number of pods, number of seeds per pod and weight of 20 seeds) are plotted on the same basis as that described for total seed yield in Figure 5a and b. These are presented in Figure 6a, b, c and d. Except for S.J.4 under treatment 3 the pattern of yield reduction of the main stem seed yield (Figure 6a) was similar to that of the total seed yield (Figure 5a and b). Except for S.J.4, the number of pods was reduced to approximately 50% of the control value even under the minor water stress treatment (treatment 3). However, there was little further reduction as the duration of water stress increased (i.e. treatment 2) (Figure 6b). For the weight of 20 seeds, it was less sensitive at treatment 3 than at treatments 2 and 4. Between treatments 2 and 4 the patterns were similar, indicating that the effect in treatment 2 was probably the result of water stress during the pod filling period, i.e. the same as that of treatments 4 (Figure 6c). The number of seeds per pod was less sensitive than the other two components in all the stress treatments (Figure 6d). Between the different soybean cultivars, it was evident that S.J.4 was different from the other three in the way it yield components respond to stress. By and large the reductions in S.J.4 were less in treatment 3 but were much higher than the others in treatment 2.

4.4 Relative Importance of Some Plant Characters in Determining Yield

Since the relative importance of different plant characters has been measured in different ways, namely coefficient of determination (increment

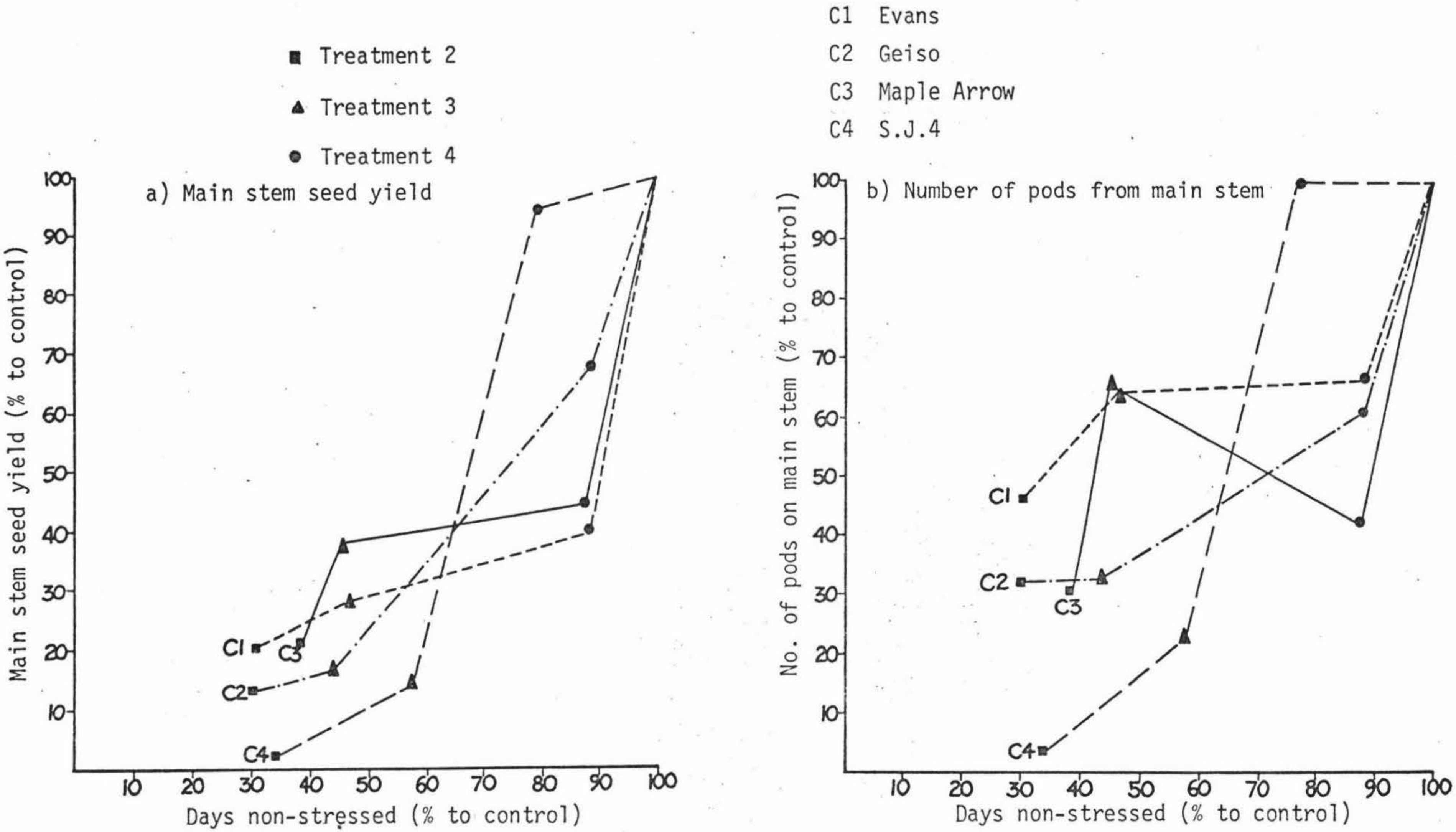
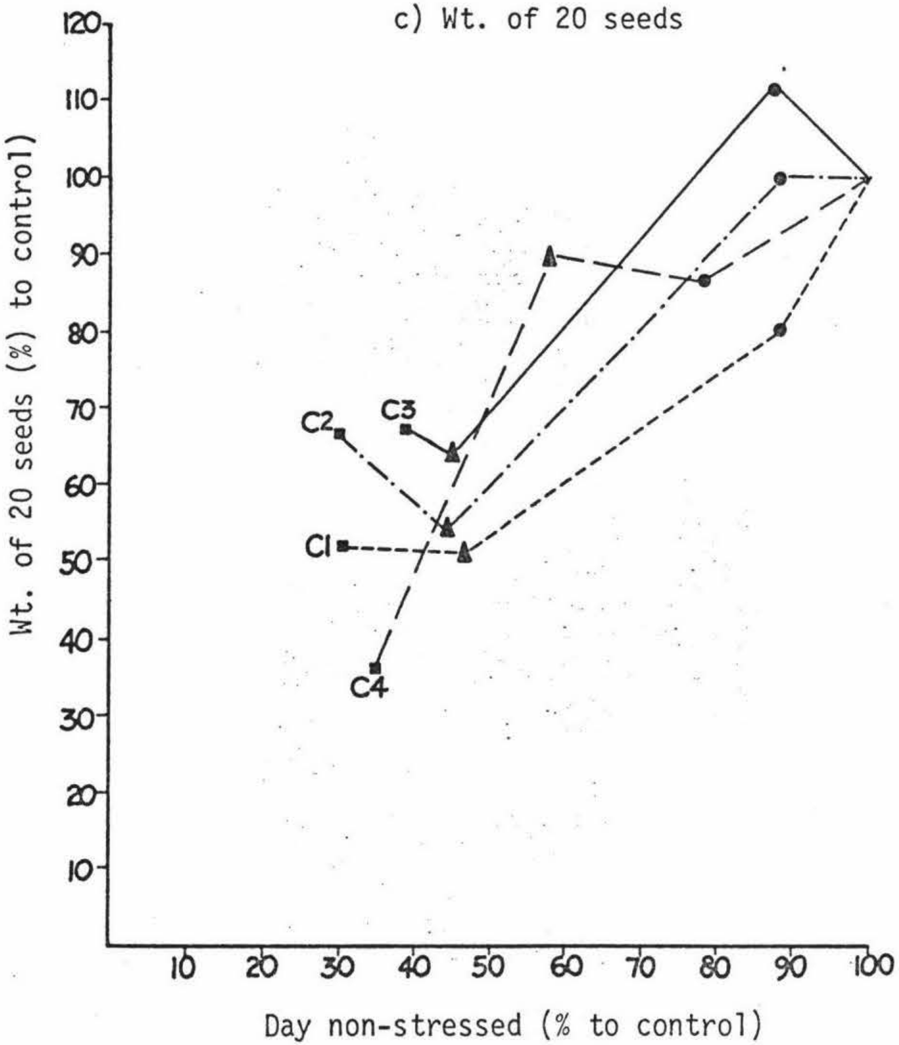
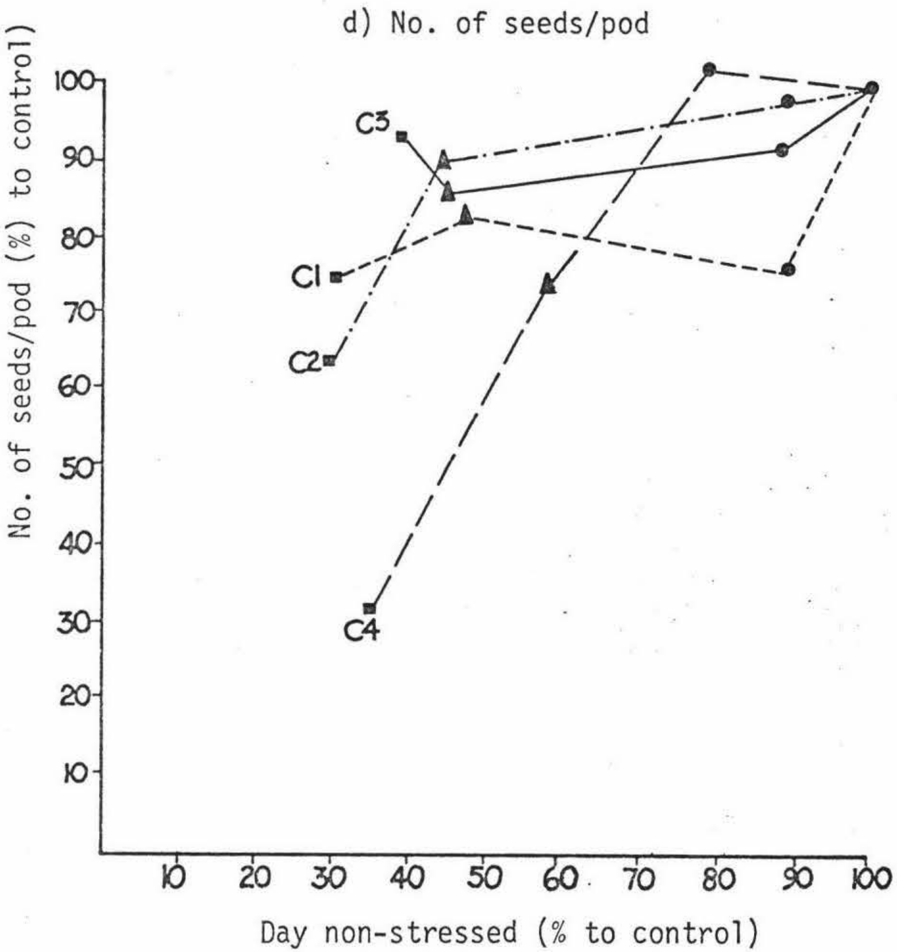


Figure 6. Normalized relationship of a) main stem seed yield and yield components b) number of pods c) number of seeds per pod d) wt. of 20 seeds express as percentage to control with percentage non stress days to control.


c) Wt. of 20 seeds
Wt. of 20 seeds (%) to control)
120
110
100
90
80
70
60
50
40
30
20
10
C1
C2
C3
C4
10 20 30 40 50 60 70 80 90 100
Day non-stressed (% to control)


d) No. of seeds/pod
No. of seeds/pod (%) to control)
100
90
80
70
60
50
40
30
20
10
C1
C2
C3
C4
10 20 30 40 50 60 70 80 90 100
Day non-stressed (% to control)

in R^2), prediction (standardized regression coefficient) and association (Partial correlation), it will be desirable to have an overall indication of this importance. Principal component analysis was used to combine the three aspects of importance to the Lagrange multiplier (λ) or the Eigenvalue and thus served as a decision making-tool. The increment R^2, the standardized regression coefficient and the partial correlation from each plant character(*viz.* number of pods, weight of 20 seeds, number of seeds per pod, number of nodes with pod, number of pods per node and number of nodes per plant) were expressed as a ratio to a base value (which in this was arbitrarily the value from the weight of 20 seeds). These were used as attributes in the principal component analysis.

Since the first few principal components (PC) usually accounted for most of the variance of the original variables, only principal components having eigen values greater than 1 were retained (Brochat, 1979). However, PC with eigen values less than 1 may also be retained. In this case, the second PC was presented if the first PC had a percentage of variance less than 70%. The associated factor structure matrix examined the meaning of a given PC in terms of the three important attributes, and gave the correlation of each PC with their original variables.

4.4.1 Comparison of cultivars across treatments

Factor structure matrix and principal component scores for the 4 cultivars are presented in table 20 and 21 respectively. The summaries of multiple regression and partial correlation are presented in appendix 5.1. From factor structure matrix (Table 20), the first principal component is the general factor in the data (i.e. high positive correlation with original variables), and was by definition the most important component. The overall relative importance of the plant characters was determined by the direct comparison of the first PC. The decreasing PC scores represented a decrease in importance. From Table 21, it can be seen that

Table 20 Factor structure matrix of principal component analysis of each cultivar.

cv. Evans

Variables	PC1	PC2	PC3
R^2	0.72344	-0.66197	0.19604
Standardized regression coefficient	0.54099	0.82422	0.16733
Partial correlation	0.97031	0.03401	0.23945

cv. Geiso

Variables	PC1	PC2	PC3
R^2	0.99000	-0.10039	-0.09909
Standardized regression coefficient	0.95051	-0.29595	0.09445
Partial correlation	0.41947	0.90755	0.01984

cv. Maple Arrow

Variables	PC1	PC2	PC3
R^2	0.99582	0.06929	0.05955
Standardized regression coefficient	0.96534	0.25458	-0.05757
Partial correlation	-0.33395	0.94252	0.01117

cv. S.J.4

Variables	PC1	PC2	PC3
R^2	0.97504	-0.21065	0.07009
Standardized regression coefficient	0.99330	-0.04268	-0.10739
Partial correlation	0.96571	0.25659	0.03968

Table 21 The principal component scores of plant characters for the 4 soybean cultivars.

Cultivar	Yield Components	PC1	PC2
Evans	No. of pods	0.843846	1.385597
	Wt. of 20 seeds	1.334663	-1.518273
	No. of seeds per pod	-1.316961	-0.447376
	No. of node with pod	0.297998	0.639770
	No. of pods per node	-0.505151	0.256265
	No. of node per plant	-0.654394	-0.315983
	Eigenvalue	1.75754	1.11869
	Percentage of variance	58.6	37.3
Geiso	No. of pods	1.758513	-0.258444
	Wt. of 20 seeds	-0.136163	1.525631
	No. of seeds per pod	-0.584253	0.383040
	No. of node with pod	-0.452676	-0.604532
	No. of pods per node	-0.585821	-1.045695
	Eigenvalue	2.05955	0.92131
	Percentage of variance	68.7	30.7
Maple Arrow	No. of pods	1.487094	-0.072459
	Wt. of 20 seeds	-0.317258	0.872695
	No. of seeds per pod	-0.627582	0.577881
	No of pods per node	-0.542254	-1.378117
	Eigenvalue	2.03505	0.95797
	Percentage of variance	67.8	31.9
S.J.4	No. of pods	1.990827	
	Wt. of 20 seeds	-0.319260	
	No. of seeds per pod	-0.488520	
	No of node with pod	-0.214828	
	No. of pods per node	-0.183151	
	No. of node per plant	-0.785069	
	Eigenvalue	2.86995	
	Percentage of variance	95.7	

except for S.J.4 all the other cultivars have retained 2 PCs.

In S.J.4 the most important character was the number of pods, with the number of pods per node and number of nodes with pod coming second and third respectively. For cultivars Evans, Geiso and Maple Arrow the plot of the two principal components was used to determine the relative importance of the plant characters (Figure 7a, b & c).

The overall importance was again determined by the direct comparison of the first PC. The second PC gave some extra information i.e. if the second PC had high positive correlation with one original variable (say partial correlation), the character with highest PC2 score, would indicate a higher association of that particular character with yield. The number of pods was the most important character in cultivars Geiso and Maple Arrow, and the weight of 20 seeds in both cultivars had a high association with yield. In cultivar Evans, the weight of 20 seeds was the most important character and the number of pods was the second.

4.4.2 Comparison of treatments across cultivars

The factor structure matrix of all the treatments is presented in table 22. The principal component scores are presented in table 23. For treatments 1, 2 and 4 the first PC was sufficient to account for the bulk of the variations and only treatment 3 had to retain 2 PCs (Table 23). The summaries of multiple regression and partial correlation are presented in Appendix 5.2.

The number of pods was the most important plant character in determining yield in treatments 1, 2 and 4. The weight of 20 seeds was second in importance for treatment 1 and the number of nodes with pods was the second important plant character for treatments 2 and 4. For treatment 3 the plot of PC1 and PC2 was presented in Figure 7d, and the weight of 20 seeds was found to be the most important character in this treatment. The number of pods was less important in this treatment than the other treatments but it still explained a large

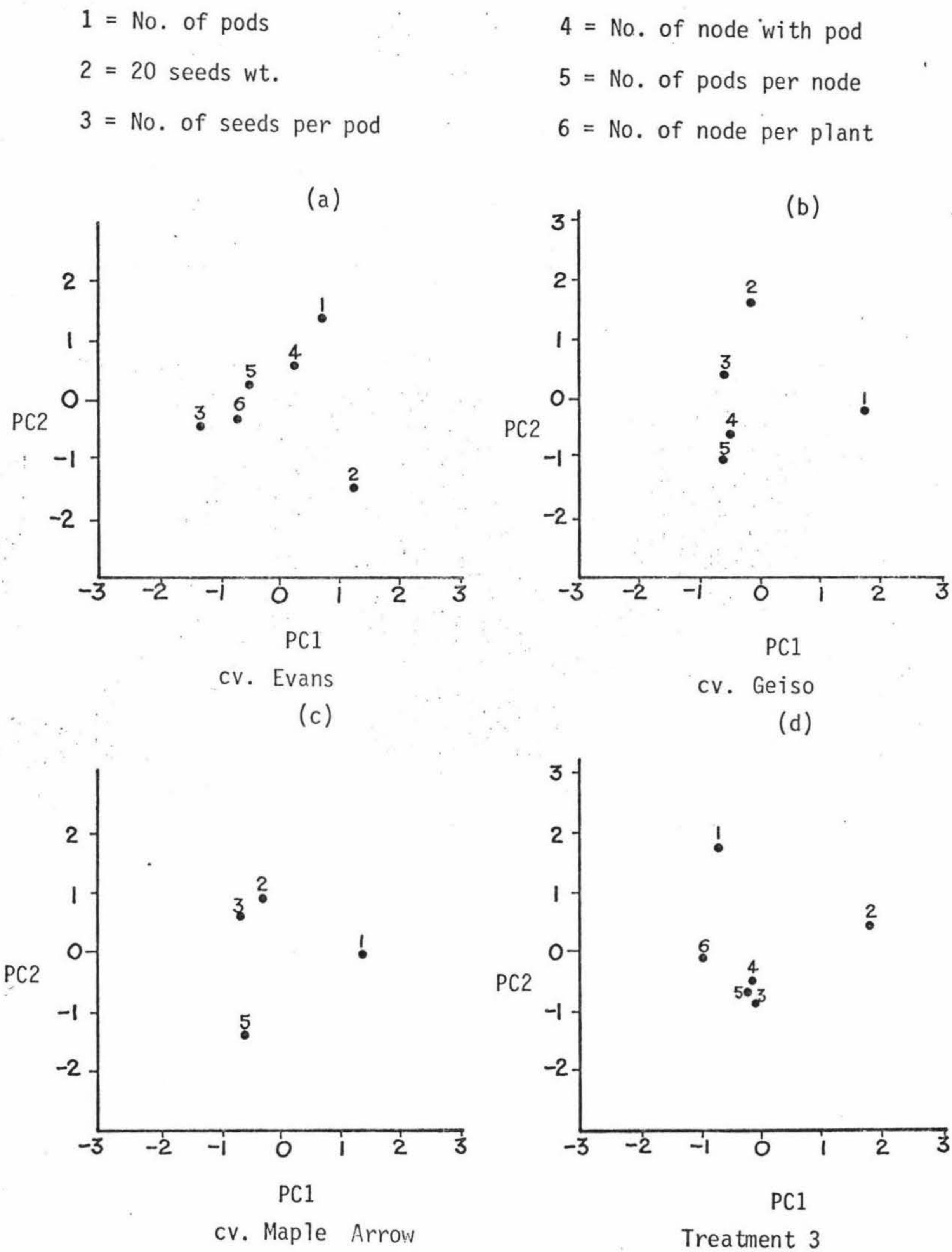


Figure 7. Principal component scores of cultivars Evans (a) Geiso (b) Maple Arrow (c) and Treatment 3 (d).

Table 22 Factor structure matrix of principal component analysis of each treatment

Treatment 1

Variables	PC1	PC2	PC3
R^2	0.89739	-0.43946	0.03952
Standardized regression coefficient	0.99327	-0.10494	-0.04893
Partial correlation	0.73144	0.68166	0.01795

Treatment 2

Variables	PC1	PC2	PC3
R^2	0.86409	0.49306	0.10118
Standardized regression coefficient	0.98137	-0.01760	-0.19130
Partial correlation	0.87743	-0.46588	0.11431

Treatment 3

Variables	PC1	PC2	PC3
R^2	0.67688	0.71245	0.18506
Standardized regression coefficient	0.90370	-0.08014	-0.42059
Partial correlation	0.79424	-0.51599	0.32085

Treatment 4

R^2	0.94154	-0.31542	0.11835
Standardized regression coefficient	0.97708	-0.16226	-0.13776
Partial correlation	0.83954	0.54259	0.02760

Table 23 The principal component scores of plant characters for the 4 water treatments.

Treatment	Yield Components	PC1	PC2
T1	No. of pods	1.196350	
	Wt. of 20 seeds	0.688998	
	No. of seeds per pod	0.080493	
	No. of node with pod	-1.261564	
	No. of node per plant	-0.704277	
	Eigenvalue	2.32692	
	Percentage of variance	77.6	
T2	No. of pods	1.767125	
	Wt. of 20 seeds	-0.397780	
	No. of seeds per pod	-0.238800	
	No. of node with pod	0.275579	
	No. of pods per node	-0.156492	
	No. of node per plant	-1.249632	
	Eigenvalue	2.47063	
	Percentage of variance	82.7	
T3	No. of pods	-0.684402	1.790172
	Wt. of 20 seeds	1.902805	0.474194
	No. of seeds per pod	-0.067354	-0.848183
	No. of node with pod	-0.105941	-0.546572
	No. of pods per node	-0.104797	-0.729897
	No. of node per plant	-0.940312	-0.139713
	Eigenvalue	1.90566	0.78025
	Percentage of variance	63.5	26.0
T4	No. of pods	1.912045	
	Wt. of 20 seeds	-0.323436	
	No. of seeds per pod	-0.252445	
	No. of node with pod	0.036445	
	No. of Pods per node	-0.345433	
	No. of node per plant	-1.027177	
	Eigenvalue	2.54603	
	Percentage of variance	84.9	

proportion of the variation in yield because it had the highest score in PC2 which had quite high positive correlation with coefficient of determination (Table 22).

4.4.3 Determinate vs indeterminate types

In order to make the comparison according to growth types, the data set was divided into the determinate growth type which included cultivars Evans and Maple Arrow, the indeterminate growth type which included cultivars Geiso and S.J.4. The factor structure matrix and principal component scores are presented in Tables 24 and 25 respectively. Only one PC was retained in both cases. The summaries of multiple regression and partial correlation are presented in Appendix 5.3. Comparison of PC1 indicated that the number of pods was the most important character in both cases. Weight of 20 seeds came second in the determinate growth type whilst the number of nodes with pods was the second in the indeterminate growth type.

4.5 Drought Tolerance Test

This test was conducted three times at different growth stages during the experiment. The first test was done at early vegetative growth stage (V3), the second test was done when the three cultivars (*viz.* Evans, Geiso and Maple Arrow) were in the first reproductive stage (R1) (S.J.4 was still in the vegetative stage). The third test was done when all the cultivars were subjected to water stress (S.J.4 was only in stage R1, when the others were about stage R4). From the results presented in Table 26, it was obvious that the younger leaf tissue was more drought tolerant than the older tissue. This could be a reflection of the stage of growth. One should remember that when the second test was done, cultivar S.J.4 was still in the vegetative stage but the other were already in the redproductive stage. In water stressed plants (3rd test) the present injury was extremely low in all the cultivars.

The detail of analysis of variance in this section are presented in Appendix 4.11.

Table 24 Factor structure matrix of principal component analysis of determinate and indeterminate growth type.

Determinate type

Variables	PC1	PC2	PC3
R^2	0.94163	-0.31747	0.11201
Standardized regression coefficient	0.97605	-0.18241	-0.11855
Partial correlation	0.59191	0.80582	0.01729

Indeterminate type

Variables	PC1	PC2	PC3
R^2	0.89451	-0.42479	0.13930
Standardized regression coefficient	0.97291	-0.03003	-0.22992
Partial correlation	0.87748	0.46632	0.11214

Table 25 Principal component scores of plant characters for the determinate and indeterminate growth types.

Type	Yield Components	PC1
Determinate	No. of pods	1.803677
	Wt. of 20 seeds	0.424607
	No. of seeds per pod	-0.236263
	No. of node with pod	-0.317444
	No. of pods per node	-0.899597
	No. of node per plant	-0.774980
	Eigenvalue	2.18970
	Percentage of variance	73.0
Indeterminate	No. of pods	1.737670
	Wt. of 20 seeds	0.121779
	No. of seeds per pod	-0.616673
	No. of node with pod	0.179685
	No. of pods per node	-0.190942
	No. of node per plant	-1.23159
	Eigenvalue	2.51668
	Percentage of variance	83.9

Table 26 Percent injury of leaf discs in 4 soybean cultivars tested at different growth stages (mean value from 3 replicates with 2 samples/replicate).

Cultivar	1st Test	2nd Test	3rd Test
Evans	51.1	73.1	12.2
Geiso	24.4	54.7	8.7
Maple Arrow	17.9	40.7	9.1
S.J.4	54.8	46.2	3.2
Significance	**	*	*
LSD 5% level	10.6	26.3	6.1

4.6 Genotype x Environment Interaction

4.6.1 Regression analysis

In this analysis, the individual cultivar yields were plotted against the mean of all cultivar yields. The regression lines of the 4 cultivars and the population mean are presented in Figure 8. The T-test between population mean ($\beta_{\bar{x}}$ = 1.0) and the other regression coefficients are presented in table 27. Regression coefficients of cultivars Geiso and Maple Arrow were not significantly different from 1, indicating that these two cultivars had general adaptability. The regression coefficient of S.J.4 was greater than 1.0 thus indicating that its yield potential would be high only under favourable conditions but its yield would be severely reduced when conditions were less favourable (i.e. water stress). Whereas the regression coefficient of Evans was less than 1.0 which indicated that it had a measure of greater resistance to environmental changes but was unable to exploit more favourable conditions. The difference between the regression coefficients of the 4 cultivars was also compared. As can be seen from Table 27, the regression coefficient of S.J.4 (1.827) was significantly greater than those of the other three cultivars.

No significant difference was found between the regression coefficients of Evans, Geiso and Maple Arrow. This was due to the large difference in standard error of each regression coefficient (i.e. Evans 0.654 ± 0.025, Geiso 0.810 ± 0.178, Maple Arrow 0.7009 ± 0.122).

4.6.2 Discriminant analysis

Firstly the discriminant analysis was done separately for each treatment, using the following ten variables: *viz*. plant length, number of nodes, number of nodes with pods, total pod weight, number of pods from main stem, total seed weight, number of seeds per pod, weight of 20 seeds, main stem seed weight and number of pods per node.

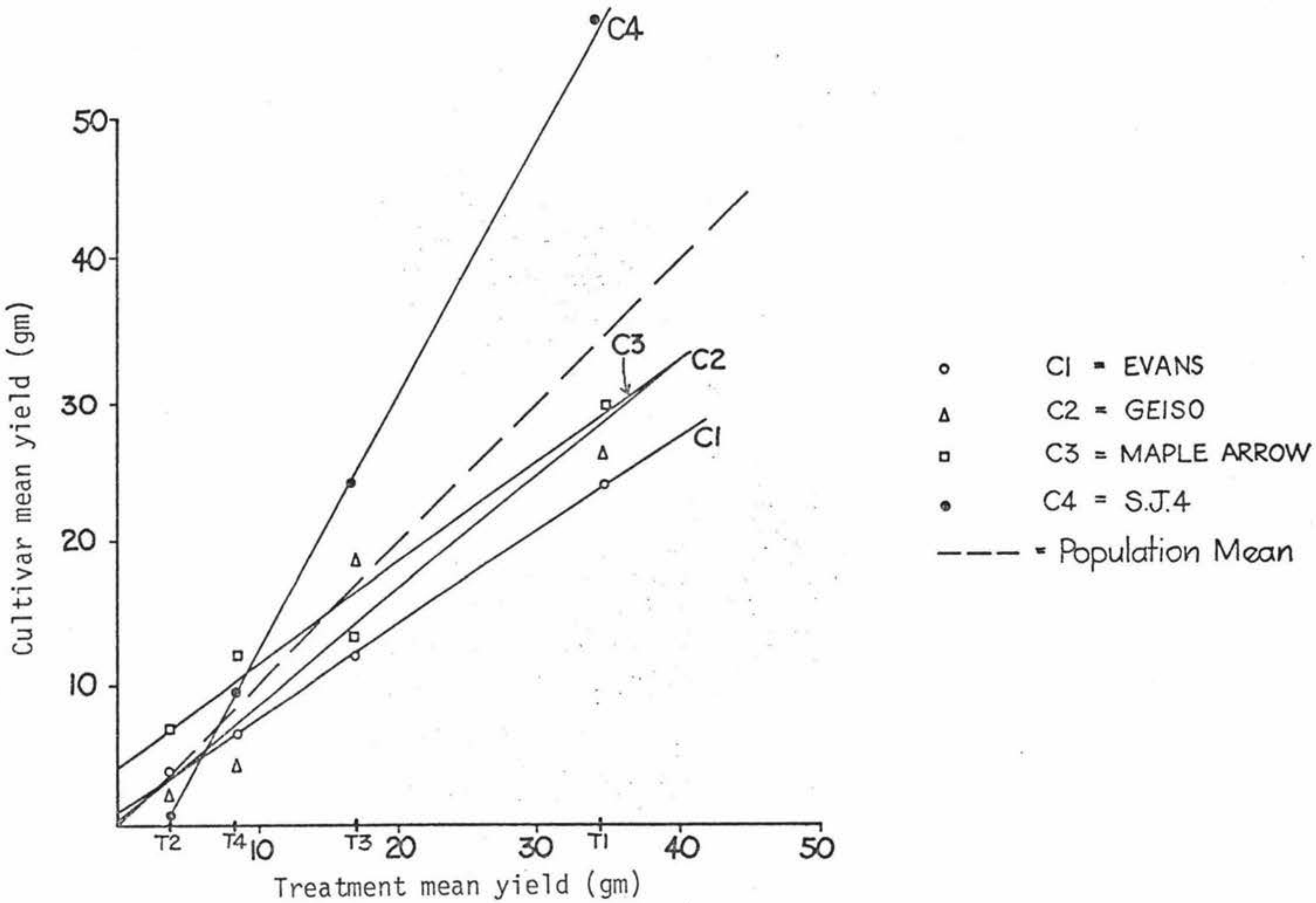


Figure 8. Regression line of 4 soybean cultivars mean yield against treatment mean yield.

Table 27 Information from linear regression of mean yield of 4 soybean cultivars regressed against treatment mean yield.

Cultivar	R^2	βi 1/	T-test $\beta 1 = 1$ (2-tailed)
Evans	.996	0.654a	****
Geiso	.912	0.810a	NS
Maple Arrow	.944	0.709a	NS
S.J.4	.999	1.827b	****

1/ statistics sharing the same letter are not significantly different ($P \leq 0.01$).

Information from the discriminant analysis for the treatments is presented in Table 28. From the test for statistical significance of discriminating information it showed that the first discriminant function was significant and could explain more than 90% of the variance in all the treatments. In treatment 1, although the second function was also significant it had only accounted for 4.6% of the variance. Therefore in this analysis only the first discriminant scores was used. In this analysis the 10 variables were taken from the individual soybean cultivars under the different water stress treatments and were combined. The resultant discriminant scores were the indices of cultivar performance under that treatment (Table 29).

This index of cultivar performance was then used as a character (converted from ten variables) in the genotype x environment interaction analysis. The principal component analysis was used, using the index of cultivar performance from the 4 treatments as the variables. The factor structure matrix are presented in table 30. The first principal component scores (PC1) had very high positive correlation with all the original variables. Only this PC1 which explained 97.4% of the variance was retained (Table 31). From the comparison of PC1, the ranking from the lowest to the highest value was Maple Arrow, Evans, Geiso and S.J.4, and it was clearly demonstrated that cultivar S.J.4 was very different from the others. However on its own these indices could not indicate the direction of that difference. Only with the prior knowledge of the different responses between different cultivars (i.e. from analysis of variance of all the variables), it could be concluded that S.J.4 was more susceptable to water stress than the other cultivars. Therefore, results from this analysis could be interpreted conclusively to represent the response of the cultivars according to their sensitivity to water stress (from low to high sensitivity), was Maple Arrow, Evans, Geiso and S.J.4.

Table 28 Information from discriminant analysis from each treatment.

Function	Eigen value	Percent of variance	Cumulative percent	Canonical correlation	After function	Chi-squared	df	Significance
From treatment 1								
1	409.98673	95.02	95.02	0.9987827	0	79.768	30	****
2	19.99541	4.63	99.66	0.9758947	1	31.619	18	*
3	1.47962	0.34	100.00	0.7724719	2	7.2649	8	NS
From treatment 2								
1	84.42377	92.29	92.29	0.9941296	0	57.810	30	***
2	5.61852	6.14	98.43	0.9213624	1	22.229	18	NS
3	1.43223	1.57	100.00	0.7673691	2	7.1105	8	NS
From treatment 3								
1	62.38052	96.37	96.37	0.9920798	0	45.447	30	*
2	1.48738	2.30	98.67	0.7732860	1	12.253	18	NS
3	0.85974	1.33	100.00	0.6799193	2	4.9635	8	NS
From treatment 4								
1	92.36115	91.30	91.30	0.9946300	0	57.997	30	***
2	8.14898	8.06	99.36	0.9437681	1	21.705	18	NS
3	0.64784	0.64	100.00	0.6270124	2	3.9957	8	NS

Table 29 Mean discriminant scores from first discriminant function of each treatment.

Cultivar	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Evans	-7.1696	-1.9783	-3.2880	-5.6476
Geiso	-10.7093	-1.7300	-2.5965	-5.7293
Maple Arrow	-12.3214	-7.9607	-5.7834	-2.9037
S.J.4	30.2002	13.2105	11.6680	14.2805

Table 30 Factor structure matrix of principal component analysis of discriminant scores.

Variables	PC1	PC2	PC3
Treatment 1 scores	0.99649	0.03699	-0.07509
Treatment 2 scores	0.98155	-0.18906	0.02865
Treatment 3 scores	0.99709	-0.07572	0.00924
Treatment 4 scores	0.97228	0.23061	0.03857

Table 31 Principal component scores (PC1) of 4 soybean cultivars from the analysis of mean discriminant scores.

Cultivar	PC1
Evans	-0.440278
Geiso	-0.415630
Maple Arrow	-0.636733
S.J.4	1.492641
Eigenvalue	3.89594
Percentage of variance	97.4

CHAPTER V

DISCUSSION

The discussion is presented in 5 parts *viz.* i) plant and soil water status ii) plant growth and development iii) yield and yield components iv) drought tolerance test and v) genotype x environment interaction.

5.1 Plant and Soil Water Status

The two basic parameters which describe the plant water status are i) the water content and ii) the energy status of water in the cell (Turner and Begg, 1981). Relative water content was used in this experiment because the technique was simple and a minimum amount of equipment was involved. These measurements were used to provide a means of defining plant water status so that the different periods of stress could be compared (Figure 1a and 1b). In this experiment the stressed plants had RWC ranging from 58 to 75% and the well water plants 87 to 96%. According to Chen *et al*.(1971) 60% RWC can be regarded as under "severe water deficit" for soybeans and RWC greater than 90% can be regarded as "well watered." So, stress treatments in this experiment were regarded as under severe stress. This could be supported by plant symptoms i.e. more than 80% of leaves wilted, high leaf abcission.

Soil moisture contents of the well watered plants were in fact higher than what were indicated in the results, this was because the plants were watered 4 times/day in the early growth stages and 6 times/day after growth stage R4. The amount of water added per pot per day was approximately 90% of the total available soil water.

5.2 Plant Growth and Development

Plant growth and development of the stressed plant differed substantially from that of the unstressed plant. Since total dry matter yield depends on the development of leaf area which intercepts the radiant energy and the rate of net photosynthesis (Turner and Begg, 1981), the difference in leaf area per plant (Table 5) reflected directly the difference in total plant dry weight. The reduction in the leaf area per plant under the stress conditions was mainly due to leaf abscission. The results showed that even under the mildly stressed treatment (Treatment 3) total plant dry weight was reduced by between 13-52% depending on cultivars (Figure 2 and Table 3). It was evident from the data sets presented in Figure 3a, b, c and d that there were further reductions in total plant dry weight when the duration of water stress was increased (i.e. in Treatments 2 and 4). However, as explained under the results Section 4.2.1 the data could not be tested satisfactorily, it was mainly due to the fact that general growth functions were incapable of properly reproducing any minor but real fluctuations that had occurred during the growth phase under study (Richards, 1969).

The cultivar difference was mainly between S.J.4 and the other three cultivars. The major difference in total plant dry weight was partly due to the longer time interval from sowing to harvesting (Table 4) and a larger leaf area in S.J.4 (Table 5). It was noteworthy that the difference between relative growth rates (RGR) for Treatments 1, and 3 were significant only in two cultivars both with indeterminate growth habits (*viz.* Geiso and S.J.4). In other words, when subjected to water stress at the reproductive stages, the longer period of vegetative growth under the indeterminate growth type resulted in greater reduction in relative growth rates than those of the determinate growth type.

The effects of water stress on final plant length and node number were most likely related to the stage of plant development when the stress was imposed. For instance, when it was imposed earlier, the effects were significant (i.e. Treatments 2 and 3) (Table 6 and 8). A similar Response was reported in soybeans by Momen *et al.*(1979) and in peas by

Maurer *et al.* (1968). The lack of significant difference in the cultivar x treatment interaction in these two characters meant that the cultivar reacted similarly to a given level of water stress. Doss *et al.* (1974) claimed that there was a positive relationship ($P \leq 0.05$) between final plant height and soybean yield in two out of three years of their study on the effects of soil water stress at the various growth stages. However, this was not the case in the present experiment because the effect on plant length depended more on the time when stress was imposed whereas yield depended largely on the duration of stress. For example, plant length from the mild stress (Treatment 3) was not significantly different from that of the longest stress period (Treatment 2) (Table 6) yet seed yield per plant was 17.1 gm and 3.7 gm for Treatments 3 and 2 respectively (Table 12). It is noteworthy that, in controlled environment chambers, a problem frequently encountered in soybean culture is the excessive stem growth which gives the plant a viny appearance not usually seen in the field (Thomas and Raper, 1978). This was the case especially for S.J.4 which had an average plant length of 184.6 cm. This was approximately double its usual length in the field. This growth pattern was also partly due to its indeterminate growth habit and its adaptation to shorter days (about 12½ hours day length). When this kind of soybean is grown under longer photoperiod it tends to be viny and the stem is longer than usual (Hinson and Hartwig, 1977). Since S.J.4 had the longest plant length it also had the highest number of branches, and only in this cultivar was the branch number per plant adversely affected by water stress (Table 7). This was probably due to the abortion of the branch primodia. The adverse effect of water stress on branch numbers in other soybean cultivars with higher branch numbers had also been reported (Momen *et al.*

1979). In soybeans, a survey of the percentage of pod bearing nodes along the main stem may be useful as a quick index on the relative efficiency of the reproductive capacity of the nodes. Results from the present experiment indicated that under water stress conditions the response of nodes bearing pods depended largely on the duration of stress. The longer the stress duration the greater would be the proportion of aborted pods (Table 9). Although S.J.4 had the lowest percentage of node with pods in all the treatment it also had the highest number of nodes (Table 8). So, the main difference in the number of nodes bearing pods came from Treatments 2 and 4. This could in part be due to the fact that S.J.4 had the longest period of stress in both treatments (Table 4). As expected, the longer period of stress also resulted in lower numbers of pods per node (Table 10). When compared with the other cultivars, S.J.4 had the lowest number of pods per node along the main stem. This was because in S.J.4 the bulk of the pods bearing nodes were located on the branches rather than on the main stem (Table 15).

5.3 Yield and Yield Components

It was clear from the literature review that the response of soybean yield depended on the timing and duration of stress in relationship to plant growth stages. As expected, the lowest yield (10% of control) came from Treatment 2 which had the longest period of stress (entire reproductive growth stages). When the reproductive growth stages were divided into early (i.e. flowering - Treatment 3) and late (i.e. pod filling - Treatment 4), results from the present experiment indicated that more reduction in seed yield occurred during the late reproductive growth stages (Table 12). This was similar to those reported by the others in soybean (Salter and Goode 1967; Doss *et al.*1974; Sionit and Kramer 1977). However cultivar difference could exist, for example, in Maple Arrow the yield from Treatments 3 and 4 were quite similar.

When water was not limiting (i.e. control treatment) S.J.4 yielded 114% more than the average of the other three cultivars. This advantage was due to the longer period of growth by this cultivar (Table 4). The same conclusions were also reported, for example, by Fehr and Weber (1971) in that the yield differences amongst cultivars were largely the result of the length of time during which dry matter accumulated in the seed. Similarly, Dunphy *et al.* (1979) found that those soybean plots which initiated flowers later and mature later tended to be the higher yielding plots.

However, evidence collected in the present experiments suggested that S.J.4 was less efficient at partitioning photosyntate to the reproductive components than the other cultivars i.e. it had the lowest ratio of pod dry weight to above ground biomass (Figure 4) and the lowest harvest index (Table 13).

When the sensitivity of yield to stress at different growth stages is examined the response seems to relate to the growth habit of these cultivars. To explain this statement the relevant factors are outlined as a flow chart in Figure 9. When water stress occurs during flowering there is good evidence that even mild water stress can reduce the rate of appearance of floral primodia i.e. in lupin by Gates (1968). The major effects of water stress at this stage is the abscission of flowers. Such results have been reported in soybeans by Show and Laing (1966), and in cowpeas by Turk *et al.* (1980). The reduction in leaf area/plant (Table 5) is also related to the reduction in yield; for example, removal of the lower leaves at early flowering of soybean at normal conditions resulted in a 20% reduction in yield (Lockwood *et al.* 1977). Depending on the growth habits difference in response occurred after the stress was relieved.

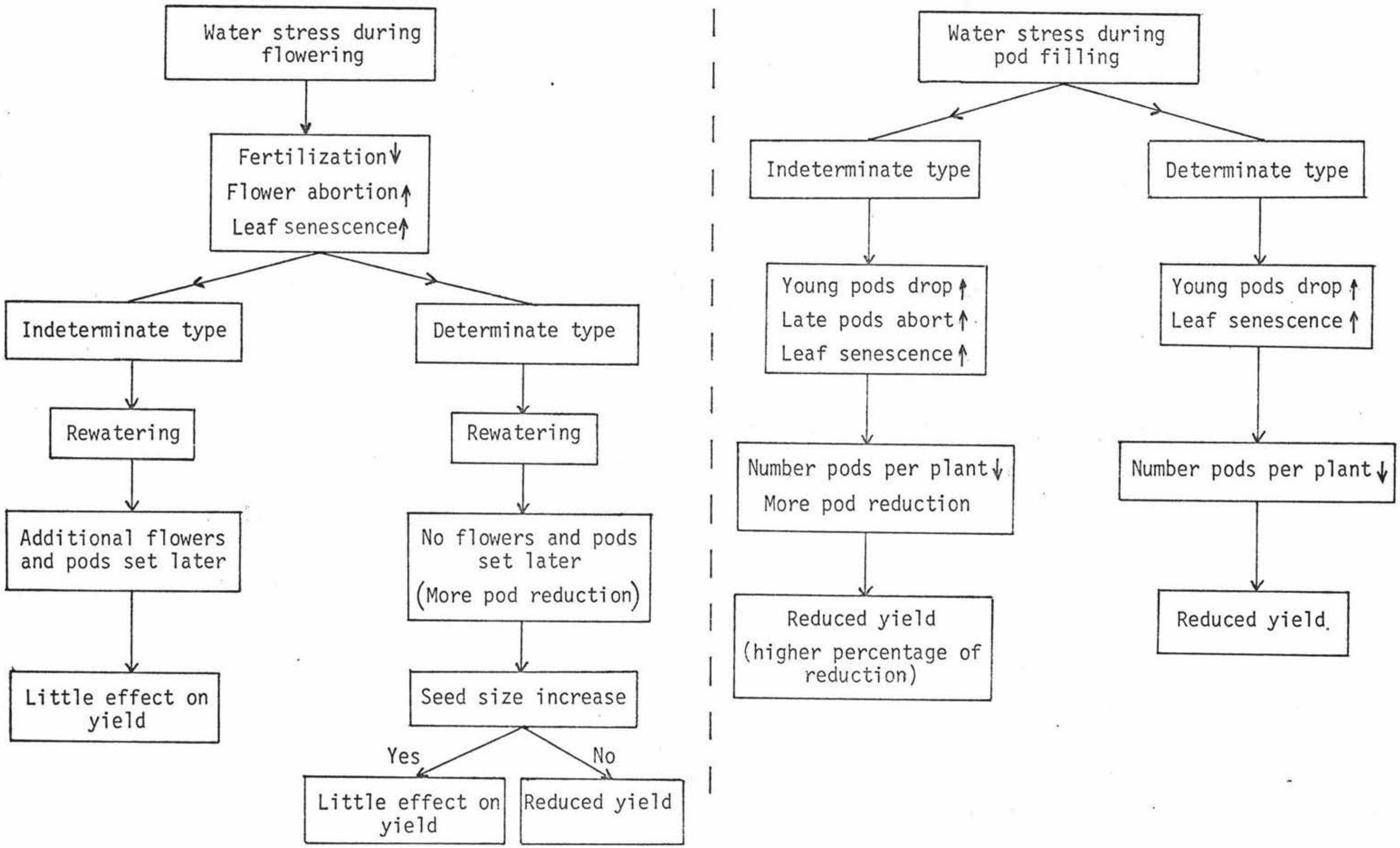


Figure 9 Flow chart of effects of water stress on two different growth types of soybeans at two reproductive growth periods.

(Vertical arrows next to variables within the rectangles indicate either increases (↑) or decreases (↓) of the variable)

The ability of the indeterminate growth types to continue to develop over several weeks has helped to reduce the yield losses due to earlier stressed conditions (Dunphy *et al.*, 1979). In the present experiment seed yields of Geiso and S.J.4 in Treatment 3 could confirm this observation (Table 12). On the other hand the determinate growth type could not adequately compensate for the earlier losses, hence seed yields of Evans and Maple Arrow were much lower under Treatment 3 (Table 12).

When water stress was imposed during the pod filling stage (Treatment 4), the indeterminate growth types (*viz.* Geiso and S.J.4) were more sensitive to water stress than the determinate types (*viz.* Evans and Maple Arrow). The main reason for the difference in response was due to a greater proportion of pod abortion in the indeterminate type (i.e. greater reduction of pods along the main stem - Table 16). The lower reduction in pod numbers in the determinate was probably because their pods had developed sufficiently to resist the effect of water deficit, whereas the developing pod in the indeterminate types was still in the sensitive stage. Furthermore, pod abortion could also occur from competition for the available photosyntate between pod development and vegetative growth (Weber, 1968). The lower harvest index for Geiso and S.J.4 in Treatment 4 when compared with that of Treatments 1 and 3 could support this statement. Thus, it can be concluded that the determinate growth types (Evans and Maple Arrow) were more sensitive to water stress during the early phase of reproductive growth (Treatment 3), whereas the indeterminate types (Geiso and S.J.4) were more sensitive during the later phase of reproductive growth (Treatment 4).

When the normalised relationship between total seed yield and the relative non-stress days was fitted by exponential curves (Figure 5a and b), it was apparent that cultivars with the indeterminate growth habits

(Geiso and S.J.4) fitted better than those with the determinate growth habits (Evans and Maple Arrow). This was mainly because of their different sensitivity to stress at different growth stages, as was discussed earlier. This difference between plant growth habits in their response to water stress should be taken into account when modelling grain losses to water stress in soybeans.

Many workers have indicated that the number of pod/plant in soybean was the most sensitive yield component affected by water stress (Shaw and Laing 1966; Wein *et al.*, 1979; Momen *et al.*, 1979; Sammon *et al.*, 1981). This has also been reported in other legumes, for example in lupin by Withers and Forde (1979) and in cowpeas by Wein *et al.* (1979). The results in the present experiment confirmed their conclusions (Tables 19, 21, 23 and 25). The sensitivity of this component to water stress depends on growth stages and growth types and has been discussed earlier as the main factor affecting yield. The number of seeds per pod was quite insensitive to water stress, for example there was no significant difference between Treatment 3 and control and between Treatments 3 and 4 (Table 17). A similar conclusion was also reported by Momen *et al.* (1979) and Sammon *et al.* (1981) on soybeans. The third yield component (average seed weight) has been reported to adjust to adverse environmental conditions i.e. in soybeans (Momen *et al.*, 1979) and in cowpeas (Wein *et al.*, 1979). The adjustment depended upon the timing of stress, for example when potential sites for dry matter storage were reduced by earlier water stress (i.e. Treatment 3) more photosyntate would be translocated into the fewer available sites resulting in larger seed. The lack of significant difference between Treatment 3 and control tended to support this (Table 18). On the other hand, when stress was imposed during the later stage of growth (i.e. Treatment 4) seed size was significantly reduced because the production and translocation of photosyntate into developing seeds were reduced

(Momen *et al.*, 1979). S.J.4 produced much smaller seeds (about 51-61% of the other cultivars) and seems to respond differently from the other cultivars. This could be due to the lower efficiency in translocating photosyntate to the seeds in S.J.4 i.e. it had the lowest ratio of pod dry weight/above ground biomass (Figure 5) and the lowest harvest index (Table 13). It was also reported that indeterminate cultivars tended to have smaller seed because the duration of the effective filling period was less for the later developed pods (Egli *et al.*, 1978). In terms of sensitivity to water stress, evidence from this experiment suggested that the three components could be ranked (from high to low sensitivity) as pod number, average seed weight and number of seeds per pod.

The relative importance of yield components and some plant characters in determining yield has been studied according to a) cultivars, b) water treatments and c) plant growth habits. The results from the comparison of the principal component scores in Section 4.4 indicated that the most important character in determining yield was the number of pods per plant. From different methods of analysis Malhotra *et al.* (1972) reached a similar conclusion. As discussed earlier the pod number was also the most sensitive yield component to be affected by water stress. In other words, in most cases yield changes under water stress conditions were mainly due to variation in pod numbers. The only deviation from this generalised conclusion was for Evans and Treatment 3. In both Evans and Treatment 3 the average seed weight was more important than the pod numbers (Figure 6a and d). Under Treatment 3, after a brief period of stress the potential sites for dry matter storage (pod number) were reduced to about the same for all cultivars (Table 16), therefore the ability to translocate more photosyntate into these sites became the major factor for yield variation rather than the number of sites. However, when the plants were subjected to a longer period of water stress (i.e. Treatments 2 and 4) both the production and translocation of photosyntate were reduced, so the ability of nodes to bear pods became more important than the average seed weight in determining yield. It is noteworthy that under indeterminate growth type, the number of nodes with pods was the second most important character in influencing yield after the pod numbers. This could partly be due to the continuation of vegetative growth for several weeks after flowering began and could increase the number of nodes with pods.

5.4 Drought Tolerance Test

Any attempt to improve the drought resistance of soybeans through genetic manipulation will require not only proper selection criteria but also a reliable procedure to screen germplasm for evidence of stress tolerance (Sammon *et al.*,1979). The ideal physiological screening test for drought resistance would be: i) highly correlated with yield ii) applicable at the early stage of development iii) rapid accurate and capable handling of large number of samples and iv) non-destructive. The drought tolerance test in this experiment seemed to be useful and meet most of the criteria mentioned above. This test was used for sorghum by Sullivan and Ross (1979) and wheat by Blum and Ebercon (1981). For this test it was found that the younger leaf tissues were more tolerant than the older tissues (Blum and Ebercon 1981). The increasing percentage injury in the second test (Table 26) could also be explained by this reason. The degree of cell injury was found to decrease in plants subjected to periods of water stress (3^{rd} Test, Table 26). This could partly be due to the cell membranes adjusting to drought stress as reported in sorghum and barley by Blum and Ebercon (1981). The difference in percent injury was greatest in the first test when the plants were in similar stages of growth (V3). Hence these values were used to determine the relationship between injury and relative reduction in yield (Table 32). The reasonably high correlation (-0.8028) indicated that this method may be used for initial screening for drought tolerance in soybean. Further investigations using a bigger collection of soybean germplasm should be conducted to confirm the usefulness of this method as a screening tool.

5.5 Genotype X Environment Interaction (GE interaction)

Two methods of genotype x environment interaction analysis (i.e. regression analysis and discriminant analysis) have been adopted in this study.

The regression analysis developed by Finlay and Wilkinson (1963) to investigate GE interaction would normally involve a wider range of genotypes and environments than that used in the present experiment (i.e. 227 varieties of barley, 4 locations and 4 years, Finlay and Wilkinson (1963)). Although in this present experiment only 4 cultivars and 4 water treatments (environments) were used, some conclusions could be drawn, for example from Figure 8, it could be seen that S.J.4 differed markedly from the other cultivars especially its yield under well water conditions (Treatment 1). S.J.4 also had higher β_1 value which suggested that it had low stability and was specially adapted to high yielding environments. Although this approach is a valuable technique, where an assessment is being made of many genotypes (Knight, 1970), the only conclusion can be drawn from this analysis is that S.J.4 is very sensitive to environmental changes (water stress treatments) and is quite different from the other cultivars.

Discriminant analysis was a relatively new multivariate technique adopted to study GE interaction. Since it was done within the treatments separately, for each treatment, the within cultivar difference was minimized while the difference between cultivars was minimized. From the principal component analysis of discriminant scores (multiple characters

Table 32 Relationship between percent injury of each cultivar with percent yield of stressed plant.

Cultivar	Percent injury 1^{st} test	Percent yield of stressed plant as percent of control
Evans	51.1	31.3
Geiso	24.4	33.9
Maple Arrow	17.9	35.9
S.J.4	54.8	20.2

Correlation coefficients -0.8028

Significance NS

performance index) it was again evident that S.J.4 was very different from the other three cultivars. The principal component scores in Table 31 were standardized scores, hence it was possible to rank the cultivar from low to high sensitivity to water stress, as Maple Arrow, Evans, Geiso and S.J.4. This conclusion could also be supported by the other parts of the results i.e. the normalized relationship of total seed yield relative to control and non-stress day (Figure 5) and the drought tolerances test (Table 32).

It can therefore be concluded that the discriminant analysis has some advantage in the study of GE interaction i.e. i) it can be done with several characters at once ii) it has no limitation in terms of the number of cultivars and environments required, like the regression method.

CHAPTER VI

CONCLUSION

From the evidence presented in this thesis, it may be concluded that:

1. The 4 soybean cultivars reacted differently to water stress. The rank of cultivars from low to high sensitivity to water stress were Maple Arrow, Evans, Geiso and S.J.4. Cultivar S.J.4 reacted differently from the other three cultivars in many aspects.

2. The growth, development and yield of soybeans were affected by water stress markedly. The response of soybean yield depended on both timing of stress in relation to growth stages and duration of stress. However some other plant characters such as plant length and number of nodes responded more to the timing of stress relative to the growth stage than the duration of stress.

3. The sensitivity of soybean yield to stress at different growth stages seemed to relate to the plant growth habits. Determinate type cultivars were apparently more sensitive to stress if it was imposed during the early phase of reproductive growth (growth stage R1 to R4) whilst indeterminate type cultivars were more sensitive to stress at the later phase of reproductive growth (growth stage R4 to R7).

4. Number of pods per plant was the most important yield component in determining yield. At least for the three cultivars Geiso, Maple Arrow and S.J.4 and it was also true for the different growth types. However the average seed weight was the most important component for cultivar Evans and also when the plants were subjected to stress at the early reproductive period.

5. The drought tolerance test may be used for initial screening of drought resistance but it should be investigated further using a bigger collection of soybean cultivars.

6. Discriminant analysis is a useful technique to study GE interaction. It provides cultivar performance index which is derived from multiple characters.

Appendix 1 Statistical symbols.

Throughout this thesis, unless otherwise stated, the following symbols were used:

NS = non significant at P = 0.05

significance levels

*	$0.05 \geq P > 0.01$
**	$0.01 \geq P > 0.005$
***	$0.005 \geq P > 0.001$
****	$P \leq 0.001$

Where the term "statistical significance" is used, unless otherwise specified, refers to 5% level of probability.

Appendix 2 Coefficient of determination (R^2) from 4 soybean cultivars from Treatment 2 and 4 when 2 growth curves were fitted with total plant dry weight.

Cultivars	Logistic curve		Gompertz curve	
	Treatment 2	Treatment 4	Treatment 2	Treatment 4
Evans	73.13	73.71	71.08	64.97
Geiso	90.73	67.07	86.58	56.19
Maple Arrow	70.28	74.54	67.79	72.50
S.J.4	70.27	81.81	74.99	80.99

Appendix 3 Method of drought tolerance test.

Leaf discs from the first fully expanded leaf of each cultivar had been cut 5 discs/cultivar/sample, placed in a test tube and washed thoroughly with distilled water to wash out the contents of cut cells and other readily diffusible electrolytes. Following the wash period the discs were submerged 10ml of 43% carbowax 6000, wt/vol, which gave an osmotic stress of about -18 bars (Sullivan and Ross, 1979). The discs were allowed to stand in carbowax solution for 24 hours, at a cool temperature (10^{o}c) to minimize secondary effects of cutting and standing. Control samples of an equal number of leaf discs were treated the same except that the carbowax was replaced with deionized water. After the treatment period, the carbowax and water from the controls was poured off and the discs quickly washed by deionized water by filling the tubes, inverting them about two times and pouring the water off. This washing process was repeated twice. 10ml of deionized water was then added to each test tube of both treated and controls, then returned to incubator 10^{o}c for 24 hours. They were then removed, warmed to 25^{o}c, shaken gently with a test tube shaker for about 5 seconds, and the conductivity of the water measured. Then the discs were killed in hot water bath of about 90^{o}c, cooled again to 25^{o}c and the conductivity of the water measured a second time.

Calculation for percent desiccation injury was performed by

if C1 = first conductivity measured

C2 = second conductivity measured.

For example

	control $\frac{C1}{C2}$ x 100	= 6% injury
∴	uninjured = 100-6	= 94%
	Treated $\frac{C1}{C2}$ x 100	= 60% injury
∴	uninjured = 100-60	= 40%
So	uninjured = $\frac{40}{90}$	= 42.6%
or	injury	= 57.4%

Appendix 4.1 Analysis of variance of plant length (cm).

Source of variation	df	SS	MS	F-ratio
Blocks	3	1967.4	655.8	2.242
Water treatment	3	16170.2	5390.1	18.424
Cultivar	3	46299.5	15433.2	52.752
Water x cultivar	9	1119.1	124.3	0.425
Residual	45	13165.3	292.6	
Total	63	78721.6		

Appendix 4.2 Analysis of variance of number of node.

Source of variation	df	SS	MS	F-ratio
Blocks	3	15.313	5.104	2.728
Water treatment	3	65.188	21.729	11.615
Cultivar	3	544.063	181.354	96.938
Water x cultivar	9	14.188	1.576	0.843
Residual	45	84.188	1.871	
Total	63	722.938		

Appendix 4.3 Analysis of variance of percentage number of node with pods.

Source of variation	df	SS	MS	F-ratio
Blocks	3	451.7	150.6	1.064
Water treatment	3	7102.4	2367.5	16.733
Cultivar	3	16803.4	5601.1	39.588
Water x cultivar	9	2980.5	331.2	2.341
Residual	45	6366.8	141.5	
Total	63	33704.7		

Appendix 4.4 Analysis of variance of number of pods per node.

Source of variation	df	SS	MS	F-ratio
Blocks	3	2.0755	0.6918	2.153
Water treatment	3	23.8480	7.9493	24.744
Cultivar	3	8.4692	2.8231	8.787
Water x cultivar	9	11.0627	1.2292	3.826
Residual	45	14.4570	0.3213	
Total	63	59.9123		

Appendix 4.5 Analysis of variance of total pod weight (gm/plant).

Source of variation	df	SS	MS	F-ratio
Blocks	3	641.65	213.88	3.190
Water treatment	3	20356.54	6785.51	101.188
Cultivar	3	6355.06	2118.35	31.590
Water x cultivar	9	7757.27	861.92	12.853
Residual	45	3017.63	67.06	
Total	63	38128.15		

Appendix 4.6 Analysis of variance of total seed weight (gm/plant).

Source of variation	df	SS	MS	F-ratio
Blocks	3	127.34	42.45	1.660
Water treatment	3	8857.45	2952.48	115.457
Cultivar	3	1218.98	406.33	15.889
Water x cultivar	9	2261.58	251.29	9.827
Residual	45	1150.75	25.57	
Total	63	13616.10		

Appendix 4.7 Analysis of variance of main stem seed wt (gm/plant).

Source of variation	df	SS	MS	F-ratio
Blocks	3	22.932	7.644	0.813
Water treatment	3	1708.269	569.423	60.553
Cultivar	3	704.384	234.795	24.968
Water x cultivar	9	280.819	31.202	3.318
Residual	45	423.170	9.404	
Total	63	3139.574		

Appendix 4.8 Analysis of variance of number of pods from main stem.

Source of variation	df	SS	MS	F-ratio
Blocks	3	449.42	149.81	2.736
Water treatment	3	5996.92	1998.97	36.510
Cultivar	3	1936.67	645.56	11.791
Water x cultivar	9	1914.39	212.71	3.885
Residual	45	2463.83	54.75	
Total	63	12761.23		

Appendix 4.9 Analysis of variance of number of seed per pod.

Source of variation	df	SS	MS	F-ratio
Blocks	3	0.07797	0.02599	0.264
Water treatment	3	3.97172	1.32391	13.435
Cultivar	3	2.98047	0.99349	10.082
Water x cultivar	9	2.92266	0.32474	3.295
Residual	45	4.43453	0.09855	
Total	63	14.38734		

Appendix 4.10 Analysis of variance of 20 seeds weight (gm).

Source of variation	df	SS	MS	F-ratio
Blocks	3	2.5412	0.8471	1.867
Water treatment	3	40.1561	13.3854	29.509
Cultivar	3	35.6378	11.8793	26.189
Water x cultivar	9	10.2498	1.1389	2.511
Residual	45	20.4121	0.4536	
Total	63	108.9969		

Appendix 4.11 Analysis of variance of percent injury from drought tolerance test.

1st test

Source of variation	df	SS	MS	VR
Blocks	2	134.90	67.45	2.419
Cultivar	3	3123.99	1041.33	37.352
Residual	9	167.27	27.88	
Total	11	3426.17		
2nd test				
Blocks	2	1538.8	769.4	7.510
Cultivar	3	1805.6	601.9	5.875
Residual	9	2420.4	268.9	
Total	11	3959.2		
3rd test				
Blocks	2	4.542	2.271	0.414
Cultivar	3	126.303	42.101	7.680
Residual	9	32.892	5.482	
Total	11	163.737		

Appendix 5.1 Summary of multiple regression and partial correlation of seed yield with selected plant characters for the 4 soybean cultivars.

Cultivar	Yield components	Regression coefficient	Increment in R^2	Standardized regression coefficient	Partial correlation
Evans	Wt. of 20 seeds	2.621	0.782	0.502	0.917
	No. of pod	1.741	0.127	2.321	0.851
	No. of seeds per pod	2.310	0.016	0.141	0.594
	No. of node with pod	-4.862	0.010	-1.253	-0.855
	No. of node per plant	1.649	0.025	0.269	0.724
	No. of pods per node	-9.568	0.020	-0.891	-0.707
	(Constant)	3.023	Total=0.980		
Geiso	No. of pods	0.876	0.912	1.459	0.776
	Wt. of 20 seeds	1.882	0.051	0.355	0.906
	No. of seeds per pod	3.305	0.013	0.202	0.710
	No. of node with pod	-1.558	0.004	-0.526	-0.587
	No. of pods per node	-3.485	0.005	-0.486	-0.514
	(Constant)	-2.081	Total=0.985		
Maple Arrow	No. of pods	0.307	0.794	0.608	0.378
	Wt. of 20 seeds	2.594	0.122	0.340	0.863
	No. of seeds per pod	8.752	0.054	0.244	0.814
	No. of pods per node	1.694	0.002	0.182	0.195
	(Constant)	-29.491	Total=0.972		
S.J.4	No. of pods	0.337	0.971	1.433	0.839
	No. of node per plant	-0.051	0.003	-0.033	-0.201
	Wt. of 20 seeds	0.574	0.001	0.142	0.450
	No. of pods per node	-0.978	0.001	-0.312	-0.464
	No. of node with pod	-0.309	0.001	-0.378	-0.416
	No. of seeds per pod	0.857	0.003	0.114	0.341
	(Constant)	0.448	Total=0.980		

Appendix 5.2 Summary of multiple regression and partial correlation of seed yield with selected plant characters for the 4 water treatments.

Water treatment	Yield components	Regression coefficient	Increment in R^2	Standardized regression coefficient	Partial correlation
T1	No. of pods	0.424	0.618	0.681	0.675
	Wt. of 20 seeds	3.360	0.285	0.515	0.967
	No. of seeds per pod	10.370	0.084	0.326	0.953
	No. of node per plant	0.267	0.004	0.116	0.556
	No. of node with pod	-0.123	0.0003	-0.034	-0.056
	(Constant)	-37.231	Total=0.991		
T2	No. of pods	0.666	0.833	1.955	0.828
	No. of node per plant	-0.014	0.020	-0.018	-0.030
	No. of seeds per pod	1.817	0.008	0.531	0.584
	No. of node with pod	-1.167	0.017	-1.218	-0.666
	No. of pods per node	-1.709	0.023	-0.689	-0.566
	Wt. of 20 seeds	0.810	0.025	0.403	0.505
	(Constant)	0.0791	Total=0.926		
T3	Wt. of 20 seeds	2.427	0.531	0.822	0.934
	No. of pods	-0.944	0.341	-0.250	-0.177
	No. of seeds per pod	4.085	0.082	0.284	0.801
	No. of node per plant	0.160	0.003	0.155	0.451
	No. of pods per node	3.636	0.005	0.503	0.589
	No. of node with pod	1.009	0.010	0.560	0.511
	(Constant)	-26.808	Total=0.972		
T4	No. of pods	0.528	0.947	1.563	0.930
	No. of node with pod	-0.767	0.022	-0.571	-0.750
	No. of seeds per pod	2.264	0.004	0.167	0.750
	No. of pods per node	-1.656	0.005	-0.276	-0.653
	Wt. of 20 seeds	1.470	0.010	0.163	0.707
	No. of node per plant	0.068	0.001	0.050	0.347
	(Constant)	-4.201	Total=0.989		

Appendix 5.3 Summary of multiple regression and partial correlation of seed yield with selected plant characters for 2 different growth types.

Type	Yield components	Regression coefficient	Increment in R^2	Standardized regression coefficient	Partial correlation
Determinate	No. of pods	0.540	0.7838	0.964	0.486
	Wt. of 20 seeds	2.516	0.1386	0.380	0.789
	No. of seeds per pod	4.486	0.0223	0.180	0.561
	No. of node with pod	-1.056	0.0029	-0.318	-0.323
	No. of node per plant	0.482	0.0027	0.104	0.156
	No. of pods per node	-0.805	0.0001	-0.079	-0.070
	(Constant)	-15.694	Total=0.9505		
Indeterminate	No. of pods	0.784	0.7151	1.917	0.870
	Wt. of 20 seeds	2.344	0.1341	0.584	0.824
	No. of node with pod	-1.662	0.0350	-1.080	-0.772
	No. of pods per node	-3.745	0.0239	-0.737	-0.694
	No. of seeds per pod	3.617	0.0320	0.357	0.588
	No. of node per plant	0.018	0.0001	0.012	0.040
	(Constant)	-1.532	Total=.9402		

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